APPENDIX : DOCUMENTATION OF CATCHEM RUNS THAT MODEL AGE 0 RED SNAPPER EXPLICITLY AND PROJECTIONS OF MODEL AGE 0 AND AGE 1 RESULTS UNDER DIFFERENT FUTURE RECRUITMENT SCENARIOS

Clay E. Porch

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Southeast Fisheries Science Center
Sustainable Fisheries Division
75 Virginia Beach Drive
Miami, FL 33149-1099

Porch (2004) assessed the status of red snapper in the U.S. Gulf of Mexico by use of various configurations of the age-structured statistical model CATCHEM. The results from that assessment consistently indicated that the stock was overfished and that overfishing was still occurring even when the definition of MSY was conditioned on current levels of offshore shrimp effort. In contrast, recent applications of the model ASAP sometimes indicated that the stock was not overfished and often indicated that overfishing was no longer occurring (Cass-Calay et al. 2005, Cass-Calay and Diaz 2005, Ortiz and Cass-Calay 2005). There are several differences between the CATCHEM and ASAP applications examined during the SEDAR7 process, both in terms of the data used and the underlying structure of the models. Two of the more glaring differences were the length of the time series used and the explicit use of the bycatch of age 0 animals by the offshore shrimp fishery. The CATCHEM runs in Porch (2004) were based on landings data extending back to 1872 and used data pertaining to age 1 and older red snapper; the implicit assumption being that the bycatch–related mortality of age 0 was negligible in comparison to natural, density-dependent effects. The ASAP runs were based on data extending back only to 1984 or 1962 and used data pertaining to age 0; the implicit assumption being that density-dependent mortality is limited to the larval phase. Unfortunately, it proved difficult to apply the ASAP model to the longer time series or data limited to age 1 and older. This appendix documents the application of the CATCHEM model to data that include age 0 animals.

Methods

The data employed and model structures used are essentially the same as described in Porch (2004) and Porch (2005) except that they explicitly incorporate age 0 animals. Thus, the bycatch time series now includes age 0 animals and the SEAMAP trawl indices for age 0 (Table x in the AW report) have been added. The SEAMAP trawl indices for age 1 were also used, but only after the mid 1980s when reliable age composition data were collected. The Beverton and Holt spawner recruit relationship was assumed, but with the understanding that it now links age 0 recruits to the spawning population during the same year. Thus, the density-dependent effects modeled by the Beverton and Holt function are essentially limited to the larval or settlement stages. Subsequent (post-settlement) mortality during the first year of life is modeled by a density-independent mortality rate coefficient (M_0) fixed at 0.98 yr^{-1}. This is in contrast to the age 1 formulation, in which case the density dependent effects are assumed to be important throughout the first year of life and are estimated.

Results

Two runs were made with age 0 modeled explicitly, one with the entire 1872 – 2003 time series (model A) and one beginning in 1984 (model B).

Model fits to data. Model A matched the total catch data quite well with the exception of the high shrimp bycatch values during some of the early years, which happen to have high CV's associated with them (Figure 1). The model fit most of the indices of abundance reasonably well (Figure 2), but could not reconcile the increasing trend in the western larval index (representing spawners) with the flat or declining trends indicated by the other western indices. The model fits to the SEAMAP trawl series show a strong residual pattern where the predictions for the early years are considerably lower than the trawl index values, and, in the case of the eastern stock, the predictions for the later years are considerably higher than the trawl index values. The mismatch for the early years can be attributed the very high CV's associated with those data. The mismatch in more recent years reflects the influence of the bycatch data, which, in the context of relatively constant effort, suggests recruitment generally has increased in the east in recent years. The shrimp effort series were fit very well (Figure 3) owing to the rather low observation CV's assigned to those data (10%). The fits to the age composition data, aggregated over all years, appear to be quite good (Figure 4). It should be kept in mind, however, that the fits to individual years are noisier, particularly where the sample size was small.

The model B fits to the data were quite similar to model A, and therefore not shown.

Parameter estimates. The estimated vulnerability and fishing mortality rates F for model A are shown in Figure 5 (patterns are similar for model B and therefore not shown). In general, the vulnerability of red snapper to the recreational and commercial hand line fleets follows a dome-shaped pattern with a peak at age 1 or 2 for the former and at age 5 for the latter. (Recall that the vulnerability coefficients reflect the probability of being caught and include undersized fish; the probability of being caught and landed is the vulnerability coefficient multiplied by the probability that a fish is greater than the size limit.) The vulnerability of red snapper to the commercial long line fleet follows a logistic pattern with older animals (10+) being the most vulnerable. The vulnerability patterns for the closed season "fleets" were between those of the hand line and longline fleets. As expected, age 0 and age 1 fish were much more vulnerable to shrimp trawls than age 2 or older.

The estimated trends in apical fishing mortality rates (the F on the most vulnerable age class) indicate persistent increases for all fleets. Although the recreational F in the east appears to have declined markedly in recent years, it remains at rather high levels. The highest fishing mortality rates were associated with the western shrimp fishery followed by the eastern recreational and western commercial handline fisheries. Of course the high shrimp bycatch rate essentially applies to only two age groups, whereas the lower apical *F'*s estimated for the handline and recreational fleets apply to multiple age classes.

There does not appear to be a strong relationship between the number of recruits and the effective number of spawners (*S*) in the previous years (see Figures 6 and 7). The estimates of the maximum potential spawn per recruit (α) were near the limit of 151 imposed by the model, which translates to steepness values of 0.974.

Estimated population trends. The Model A estimates of historical trends in the relative spawning potential and age 0 recruits are shown in Figure 6. The Model B estimates are shown in Figure 7. Under pristine conditions, the western population of red snapper in U.S. waters is estimated to have been about five times larger than the eastern population. Both populations are estimated to have been heavily overfished by 1962, consistent with the results obtained with the age-1 runs (i.e., when the age 0 animals were omitted).

Interestingly, the estimates of recruitment during the latter part of the time series are substantially larger than the estimates of virgin recruitment R_0. Numerous mechanisms that could account for such a change were discussed during the SEDAR assessment and review workshops, including density-dependent mortality effects; reduced predators; more favorable oceanographic conditions; increased pre-recruit habitat (oil rigs, artificial reefs and other habitat expansions); and the possibility that the stocks extends geographically well beyond the U.S. Gulf of Mexico (e.g., Campeche Banks). These are all valid research topics for the next several years, and at this point it seems premature to focus on one to the exclusion of the others. Current data seem unlikely to support serious estimation for any of these effects.

The main differences between Models A and B are attributable to the estimates of virgin recruitment R_0. In the case of Model A, the estimates were 6.7 and 30.6 million for the east and west, respectively. In the case of Model B, they are several times higher at 16.6 and 230 million (Figure 7). Accordingly, the estimates of MSY from Model B are also several times higher than for Model A. For example, consider the case where MSY is conditioned the estimated spawner-recruit relationship and current (2001-2003 average) levels of bycatch effort (offshore shrimp trawling and closed season), hereafter referred to as MSY{current shrimp}. Under Model A, MSY{current-shrimp} is estimated to be 3.3 mp for the east and 4.5 mp for the west, but under Model B, MSY{current-shrimp} is estimated to be about 9 mp in the East and 31 mp in the West. On the other hand, the relative condition of the stock appears worse under Model B. Under model A, the current fishing mortality rate is estimated to be about 2.4 times F_{MSY}{current-shrimp} and the relative spawning potential of the east and west stocks in 2003 is estimated to be 45% and 37% of S_{MSY}{current-shrimp}, respectively. Under model B, the current fishing mortality rate is estimated to be about 2.9 times F_{MSY}{current-shrimp} and spawning in the east and west is estimated to be 14% and 5% of S_{MSY}{current-shrimp}, respectively. The reader should keep in mind, however, that model B had some difficulty finding a global minimum; sometimes settling on local minima with nearly the same objective function values but very different implications (including solutions with highly unrealistic levels of virgin recruitment and MSY, as was also the case with the ASAP model used during the previous assessment). For this reason, the RW did not consider Model B further and all subsequent discourse will refer to Model A except as otherwise noted.

Choice of reference points. The potential for recovery of course depends on the way the benchmark is defined. To this point only *F* and *S* levels associated with MSY{current-shrimp} have been shown. The use of this reference point assumes, among other things, that (a) the relative allocation of effort among directed fleets remains constant at current levels, (b) the absolute allocation of effort among offshore shrimp trawlers and closed season fishing operations remains the same, and (c) future recruitment will generally be in accordance with the estimated spawner-recruit relationship. One alternative is to modify assumption (b) to reflect a prescribed reduction in offshore shrimp trawling relative to current (2001-2003) levels. The RW supposed that the most likely reduction would be about 40% in accordance with the results of a recent economic forecast (Travis and Griffin, 2004). In that case the equilibrium landings, hereafter referred to as MSY{40% reduced-shrimp}, amount to 3.7 million lbs for the east and 7.8 million lbs for the west. Spawning levels in the east and west are estimated to be 44% and 24% of S_{MSY}{40% reduced -shrimp}. Current levels of fishing mortality are estimated to be 2.1 times greater than F_{MSY}{40% reduced-shrimp}. Another alternative is to define MSY in terms of the entire fishery, assuming the effort of all fleets, both directed and undirected, can be scaled down by the same proportion (i.e., all fleets, directed and bycatch, are governed by assumption a). In previous assessments this has been referred to as the “linked-selectivity” or “policy neutral” approach because all fleets endure the same proportional reduction in effort (technically this is policy-neutral only with respect to red snapper, other important concerns notwithstanding). The corresponding equilibrium landings, hereafter referred to as MSY{equal-proportions}, are 5.2 and 15.6 million lbs for the east and west, respectively. Spawning levels in the east and west are estimated to be 16% and 6% of S_{MSY}{equal-proportions}.

Plots of stock status with respect to the benchmarks discussed above are compared with the corresponding plots for the age-1 model in Figure 8. Overall, the results for the models with and without age 0 are very similar; the stocks in the east and the west are estimated to be overfished regardless of the benchmark used. The degree to which each stock is overfished depends, of course, on the choice of benchmarks used to define MSST. The perception of stock status is least optimistic when the reference point used is S_{MSY}{equal-proportions}, which tends to be between 25 and 30% of S_0. The perception of stock status is better (less-overfished) when S_{MSY}{current-shrimp}or S_{MSY}{40% reduced-shrimp} are used as reference points inasmuch as they are a much lower fraction of S_0. The values of S_{MSY}{current-shrimp}and S_{MSY}{40% reduced-shrimp} for the east are both about 10% of S_0 because the bycatch of red snapper in that region is relatively small. The values of S_{MSY}{current-shrimp}and S_{MSY}{40% reduced-shrimp} are lower for the west (about 5% and 7%, respectively) because the bycatch there constitutes a much larger fraction of the total kill.

Other alternative definitions of MSY can be devised based on modifications to assumption (c), which concerns future recruitment. The Review Workshop recommended that MSY-related benchmark statistics and advisory forecasts reflect the apparent increase in recent recruitment over the levels expected based on the estimates of R_0. Specifically, they recommended determining future recruitments using a Beverton-Holt spawner recruit curve with the estimated steepness of 0.974, but a new R_0 equal to the average of the recruitment estimates for the period from 1984 to 2003. This approach, of course, implies that the mechanisms bolstering recent recruitment will continue into the foreseeable future. Plots of stock status when recent levels of recruitment are used to define the benchmark are shown for the three MSY allocation strategies discussed above in Figure 9. Again, the results for the models with and without age 0 are very similar; the stocks in the east and the west are estimated to be overfished regardless of the benchmark used. More importantly, the extent to which the stock appears overfished is greater under the "recent R_0" scenario than under the "estimated R_0" scenario (Figure 8) because the future productivity of the stock is deemed to have increased. In other words, both S_0 and S_{MSY} increase in proportion to the increase in R_0 (the steepness being near 1), therefore both S_{2003}/S_0 and S_{2003}/S_{MSY} decrease.

A more stable and potentially less risky policy than MSY might be based on maintaining a particular spawning potential ratio (SPR). While the fishing mortality rate associated with a given SPR ($F_{\%SPR}$) depends on the current vulnerability pattern, the corresponding long-term spawning potential ($S_{\%SPR}$) does not. For this paper the value of $F_{\%SPR}$ is chosen so that the SPR value of the most affected stock is equal to the desired level; the SPR level achieved by the remaining stock being greater than or equal to the desired level. Inasmuch as the steepness is near 1, the value of S/S_0 and SPR are nearly equivalent. Hence, stock status with respect to a 30% SPR policy can be inferred from the horizontal line at $S/S_0 = 0.3$ in Figures 8 and 9. Note that 30% SPR levels cannot be attained even in the absence of any directed harvest unless offshore shrimp effort is reduced from current levels by more than 40%.

Projections. The RW in fact identified three possible scenarios for future recruitment. Each scenario employed the Beverton-Holt relationship with a steepness of 0.974, but the level of virgin recruitment R_0 was set to one of three values: (1) the 'historical' level estimated with the long time series, i.e., Model A; (2) the 'recent' average of the recruitment estimates for 1984-2003 from Model A; and (3) the 'high' values estimated with the short time series, i.e., Model B (as an upper limit). Projected trends in the relative spawning potential S/S_0 are shown for Model A under various levels of total allowable catch (TAC) in Figure 10. In all cases the current TAC of 9.12 mp is projected to permit recovery to MSY{40% reduced} by 2032, but in no case will the stock in the west recover to values of S/S_0 equal to 0.3 (with high steepness the value of S/S_0 is roughly equivalent to the value of SPR). For comparison, similar TAC plots are shown in Figure 11 for the equivalent age-1 model. In this case, the current TAC is projected to lead to near extirpation of the stock unless recent levels of recruitment persist into the future.

Figures 12-15 present S/S_{MSY} and S/S_0 isopleths generated from projections to the years 2010 and 2032 under various levels of directed harvest (Gulf-wide total allowed landings or directed fishing mortality rate) and percent reductions in effective offshore shrimp effort (relative to current, 2001-2003, levels). The numbered contour lines represent the value of S/S_0 expected during the given year (2010 or 2032). The colors represent the magnitude of S/S_{MSY}: Red indicates that the value of S/S_{MSY} is less than 1.0 (not yet recovered); yellow indicates S/S_{MSY} is at least 1.0, but less than 4.0; and green indicates S/S_{MSY} is greater than 4.0. value. Here S_{MSY} is conditioned on the current state of the fishery as described for S_{MSY}{40% reduced-shrimp}, except with a percent reduction in offshore shrimp effort equal to the value given on the horizontal axis. For example, one can infer by moving upwards along the left axis of Figure 12b that a Gulf-wide TAC of 7 mp would be expected allow S to recover to just above S_{MSY}{current-shrimp} by 2032 if the age-0 model is correct and future recruitment is governed by the 'historical R_0' scenario. The value of S/S_0 at that point, however, is only about 10%, which is rather low in comparison to the standards suggested for other long-lived species. If one were to adopt a higher standard, say $S_{30\%}$, then the effort of the offshore shrimp fishery would need to be reduced by more than 70% in order for the western stock to recover under a 7 mp Gulf-wide TAC.

It is evident from the isopleths that a wide range of TACs could allow recovery, depending on the standard the stocks are expected to recover to and the allocation between the directed and bycatch fleets. Higher TACs depend upon lowering the effective shrimp mortality of red snapper. It is therefore impossible to recommend TACs without clear guidance from the Council on the most appropriate reference point or level of shrimp trawl bycatch that should be assumed in the calculations. However, it is recommended that due to uncertainty over the current stock-recruitment relationship and due to the large differences in biomass levels which would associate with long-term maximum yields (*i.e.* landed weight) by the fisheries under certain methods for benchmark calculations, that MSY proxies based on SPR of 30% be applied in this case.

Assuming future recruitment remains, on average, at recent levels, projections of the model formulation which includes age 0 catch indicates Gulf-wide 30% SPR could be achieved by 2032 under TACs ranging from 2-9 million pounds if shrimp effort could be further reduced by 40-70%, respectively, from recent levels (Figure 13a). Ignoring age 0 catch and assuming recent recruitment levels into the future indicates Gulf-wide 30% SPR could be achieved by 2032 under somewhat lower TACs ranging from 2-7 million pounds, if shrimp effort could be further reduced by 40-70%, respectively, from recent levels (Figure 14a). Should future recruitment return to lower, historical levels, somewhat lower TACs would be required to achieve the recommended benchmark for equivalent additional reductions in shrimp effort in the same time-frame.

Summary

The age-0 model preferred by the RW, by virtue of its use of the Beverton-Holt curve to relate age 0 recruits to spawning potential in the same year, makes the implicit assumption that density-dependent natural mortality processes are important only in the planktonic phase and are otherwise unimportant compared to shrimp bycatch. It also makes the explicit assumption that the density-independent natural mortality rate M_0 is about 0.98 yr^{-1}. In contrast, the age-1 model, by virtue of its use of the Beverton-Holt curve to relate age 1 recruits to spawning potential in the previous year, makes the implicit assumption that density-dependent natural mortality processes are more important than shrimp bycatch during the first year of life. Moreover, the density-independent natural mortality rate M_0 is essentially estimated as part of the Beverton-Holt spawner-recruit relationship, rather than fixed to 0.98 yr^{-1}. Not surprisingly, the age-0 model attributes greater importance to the shrimp fishery than does the age-1 model, as evidenced by the steeper isopleths in Figures 12-13 compared with those of Figures 14-15. Both models suggest that the stock will not recover to an SPR of 30% by 2032 unless offshore shrimp trawling is reduced by an additional 50 percent. The two models differ, however, on the level of TAC needed to achieve a recovery. For example, if future recruitment follows the estimated "historical' Beverton and Holt relationships, then the age-1 model suggests the TAC would need to be reduced to about 3 mp with a 70% reduction in shrimp effort (Figure 14b) whereas the age-0 model suggests that a TAC of about 6 mp would suffice (Figure 12b).

The RW also recommended that future recruitment levels in the projections be conditioned on relatively high recruitments estimated for the last two decades (1984-2003). This of course implies that the high recent recruitments resulted from a change in the environment and that this change would likely persist into the foreseeable future. Previously, it had been assumed that the recent high recruitments were anomalous and that future recruitment would be more likely to follow the estimated "historical' Beverton and Holt relationships. As might be expected, the shift to projecting recent recruitment levels had little effect on the advice given in regards to reductions in directed effort (compare for example, Figures 12d and 13d) or shrimp trawl effort (the results still suggest the stock will not recover to an SPR of 30% by 2032 unless offshore shrimp trawling is reduced by an additional 50 percent). On the other hand, the shift to projecting recent recruitment levels has a great impact on the advice generated in regards to a TAC. This is easily seen in Figures 10 and 11, where a 9 million pound TAC is projected to allow a rapid increase in stock size when high recruitment levels are assumed and little increase (age-0) or a decline (age-1) when 'historical' recruitment levels are assumed. Essentially, a given level of TAC corresponds to much reduced fishing effort in the new, higher recruitment regime.

Finally, it is important to emphasize that the perception of recovery depends greatly on the reference point being used as the standard. One option is to base the MSST on an MSY-based reference point that is conditioned on current shrimp bycatch rates or some prescribed reduction thereof. When this is done, and the shrimp bycatch is reduced to the degree expected, the stock can attain MSY by 2032 with little or no reduction in TAC (depending on the choice of models). However, economic forecasts of the potential reduction in shrimp bycatch are only about 40%, in

which case the SPR values associated with the conditional MSYs are on the order of 10 percent or less. Such low values of SPR are considered very risky for long-lived species in most other arenas. If, on the other hand, a more reasonable SPR of 30% were targeted, then the current 9.12 mp TAC would not be justifiable unless offshore shrimp trawl effort were reduced by at least 70% from current levels. The TAC required to achieve a given SPR depends on whether the objective is to achieve that SPR on a Gulf wide basis or for each stock independently. Due to the greater impact of the shrimp fishery in the western Gulf, a lower TAC is required to ensure the recovery of the western stock than for the eastern Gulf or both stocks combined. If the management goal is to rebuild the each stock to an SPR of 30% by 2032, then the TAC and shrimp reduction levels be based on the stock specific isopleth diagrams. For example if the shrimp trawl effort were reduced by 60%, then the TAC that would allow recovery would be expected to lie between 1 mp (age 1, historical recruitment levels, Fig. 14b) and about 8 mp (age 0 model, recent recruitment levels, 13b). However it is important to remember that the economic forecast (Travis and Griffin 2004) project much less than a 60% reduction in shrimp effort.

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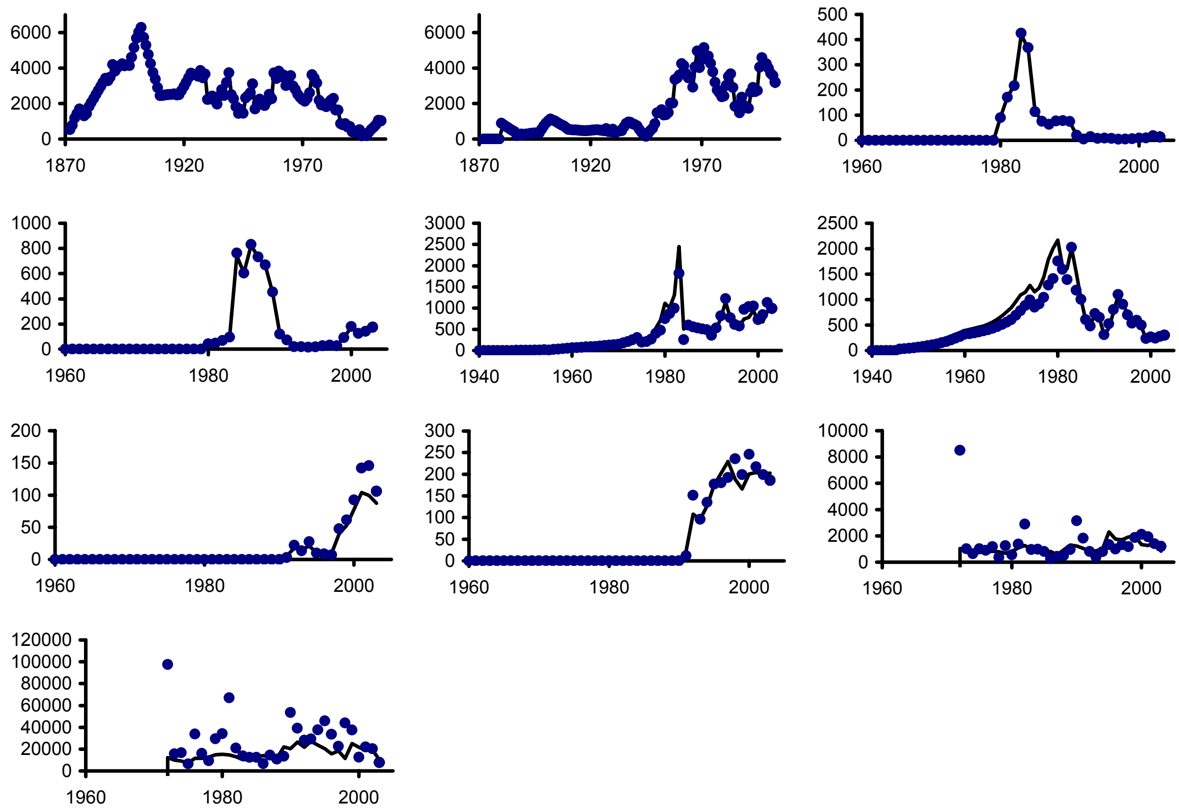


Figure 1. Model A (1872-2003) fits to the total landings in weight for the handline (HL) and longline (LL) fleets, total number landed for the recreational fleet (REC), and total number killed for the closed season (CLSD) and shrimp bycatch for east E and west W.

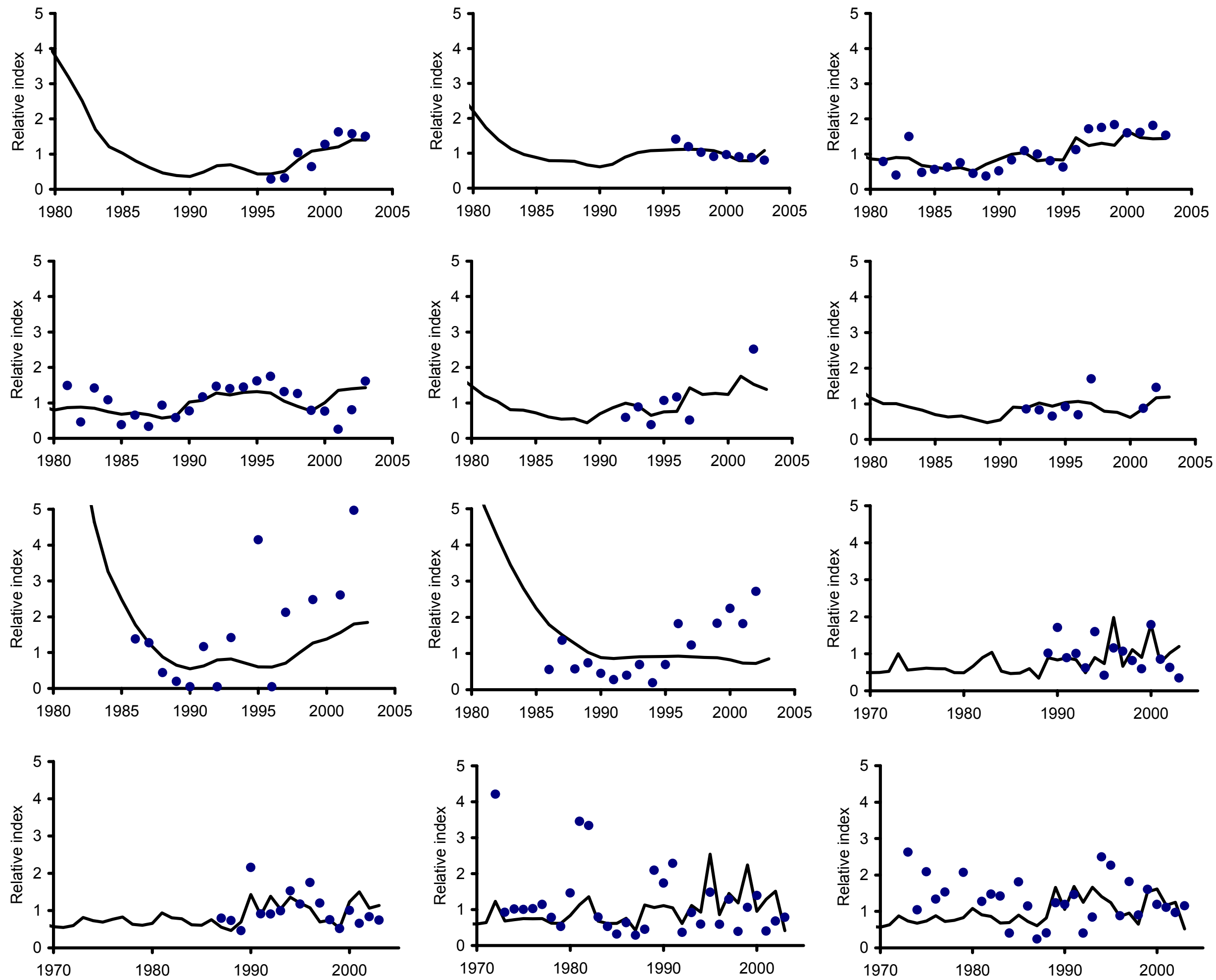
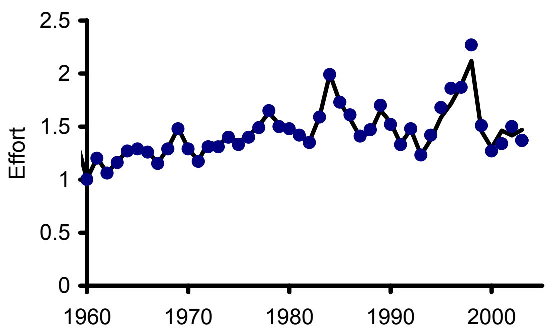


Figure 2. Model A (1872-2003) fits to indices of abundance (rescaled by the mean of the predicted values).



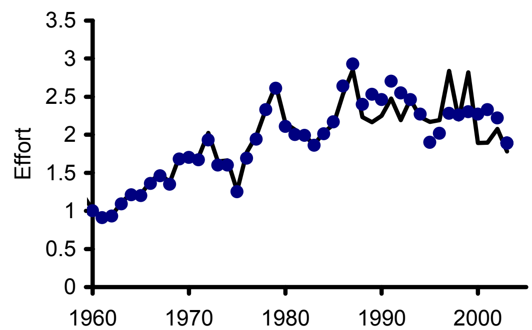


Figure 3. Model A (1872-2003) fits to the shrimp trawl effort series.

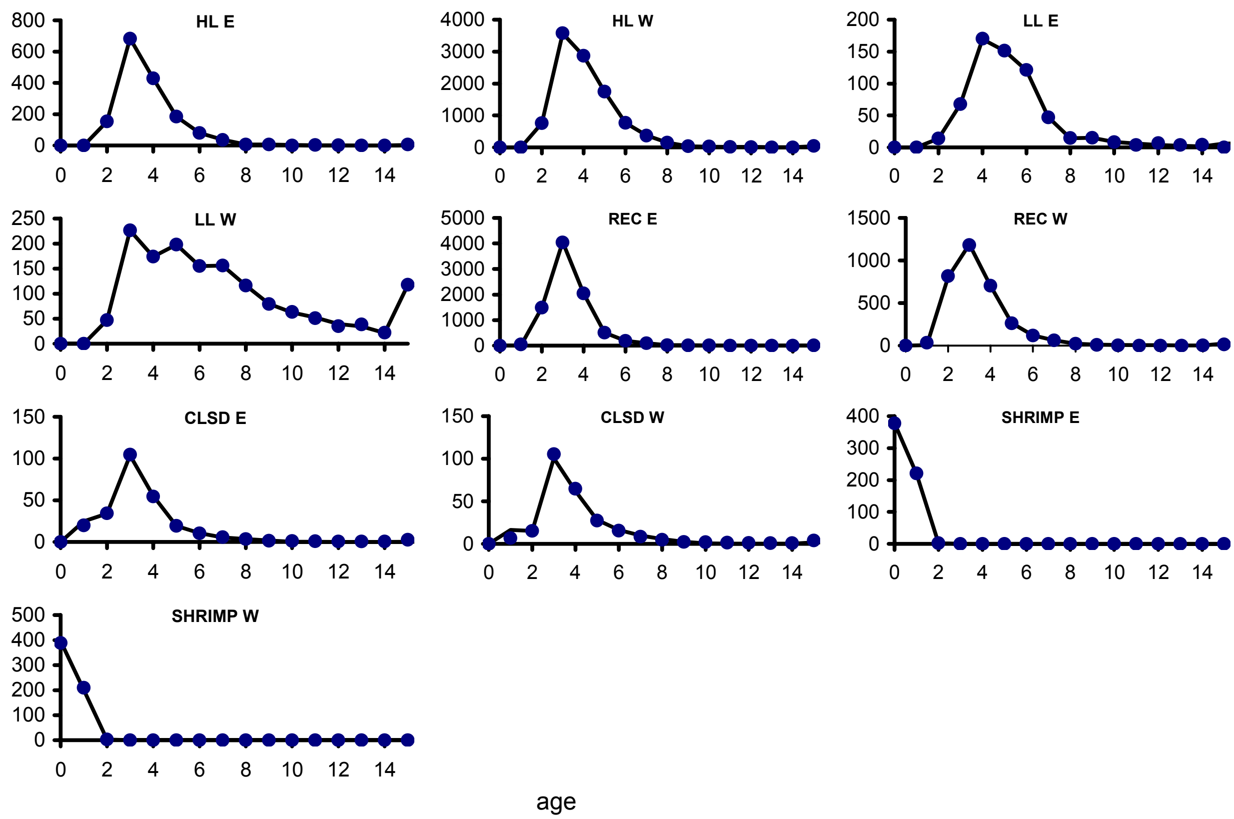
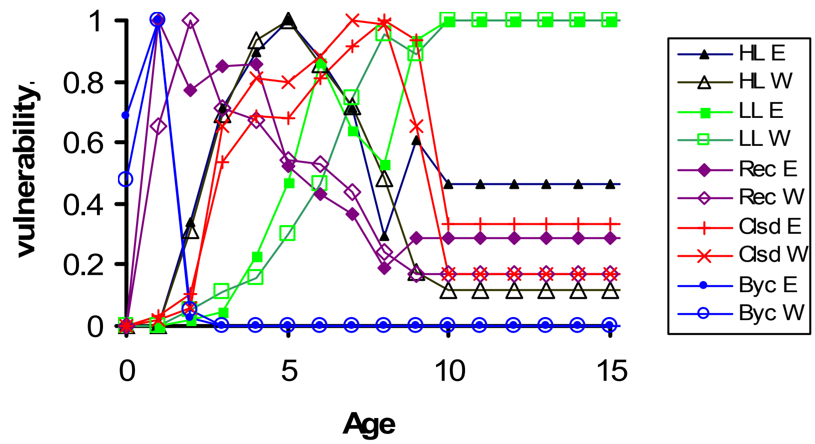


Figure 4. Model A (1872-2003) fits to the age composition data (aggregated across years).



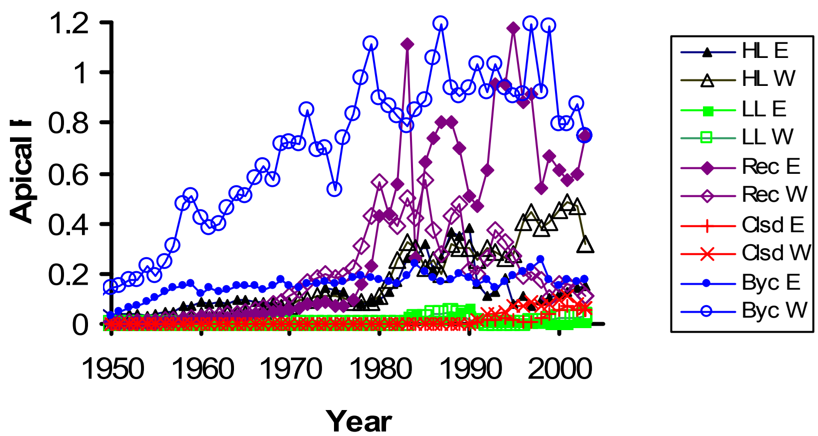


Figure 5. Model A (1872-2003) estimates of vulnerability and apical fishing rate by fleet.

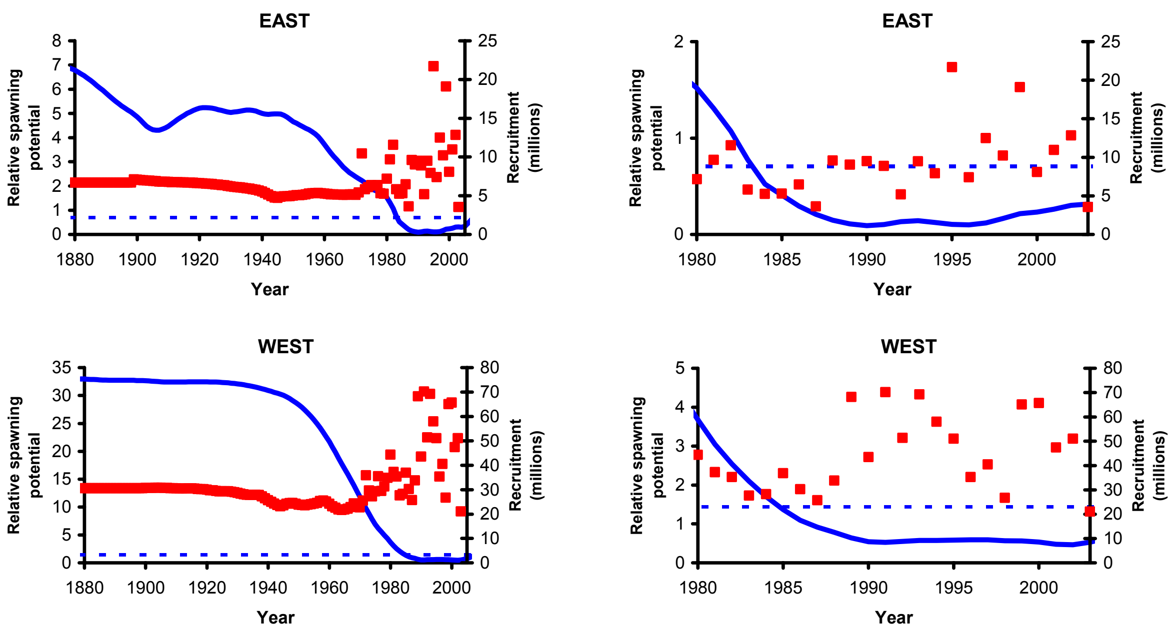


Figure 6. Model A (1872-2003 time series) estimates of the relative spawning potential (lines) and corresponding number of age 0 recruits (squares). The horizontal line gives the relative spawning potential associated with MSY{current-shrimp}. Panels to the right focus on the latter part of the time series.

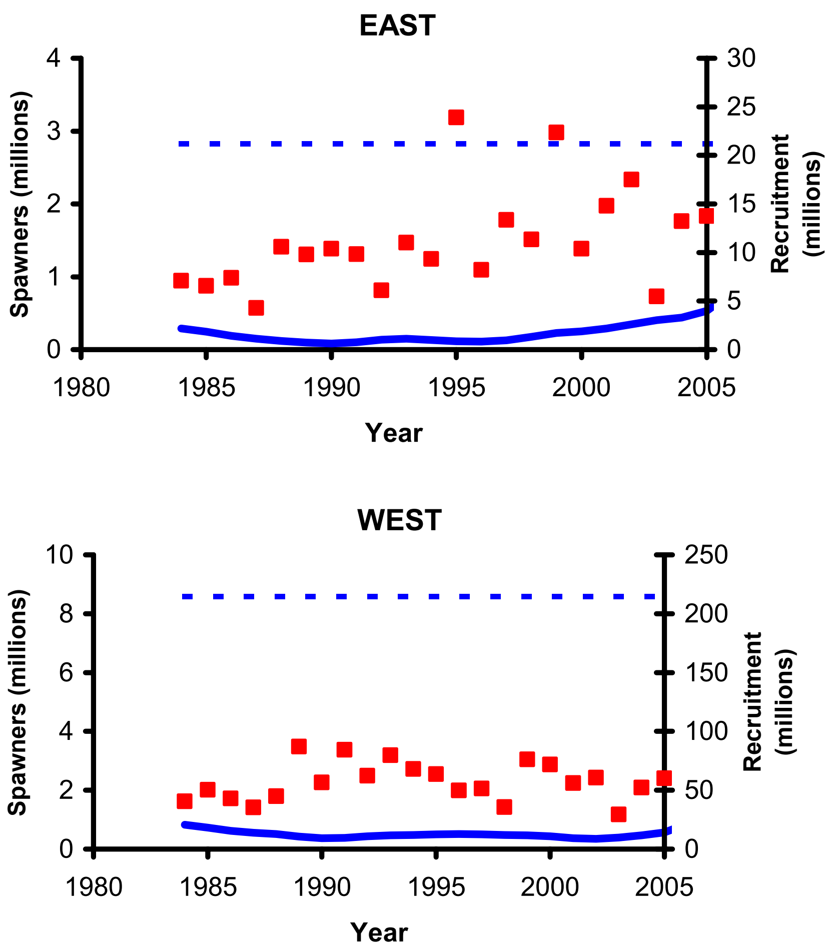


Figure 7. Model B (1984-2003 time series) estimates of the relative spawning potential (lines) and corresponding number of age 0 recruits (squares). The horizontal line gives the relative spawning potential associated with MSY{current-shrimp}.

R_0 = model estimate

Age 0 included (RW) | **Age 0 excluded (AW)**

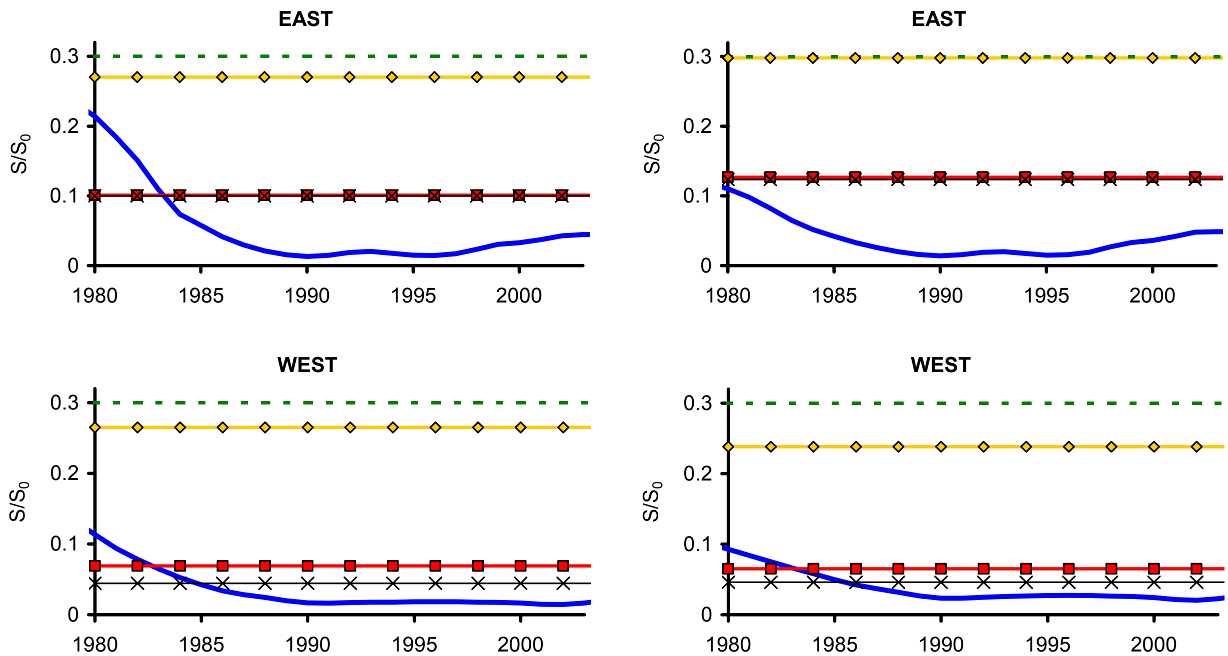


Figure 8. Trends in spawning potential relative to virgin levels (S/S_0, blue curve) compared with four benchmarks based on the estimated spawner-recruit relationship: $S_{30\%}$ = dashed green line; S_{MSY}\{equal proportions\} = gold diamonds; S_{MSY}\{40% reduced shrimp\} = red circles; and S_{MSY}\{current shrimp\} = black x's. The panels on the left give the results obtained when age 0 fish are modeled explicitly, with the implication that accounting for the bycatch of age 0 is more important than accounting for post-settlement density-dependent processes. The panels on the right give the results obtained when age 0 fish are *not* modeled explicitly, with the implication that accounting for the bycatch of age 0 is less important than accounting for post-settlement density-dependent processes.

R_0 = recent recruitments

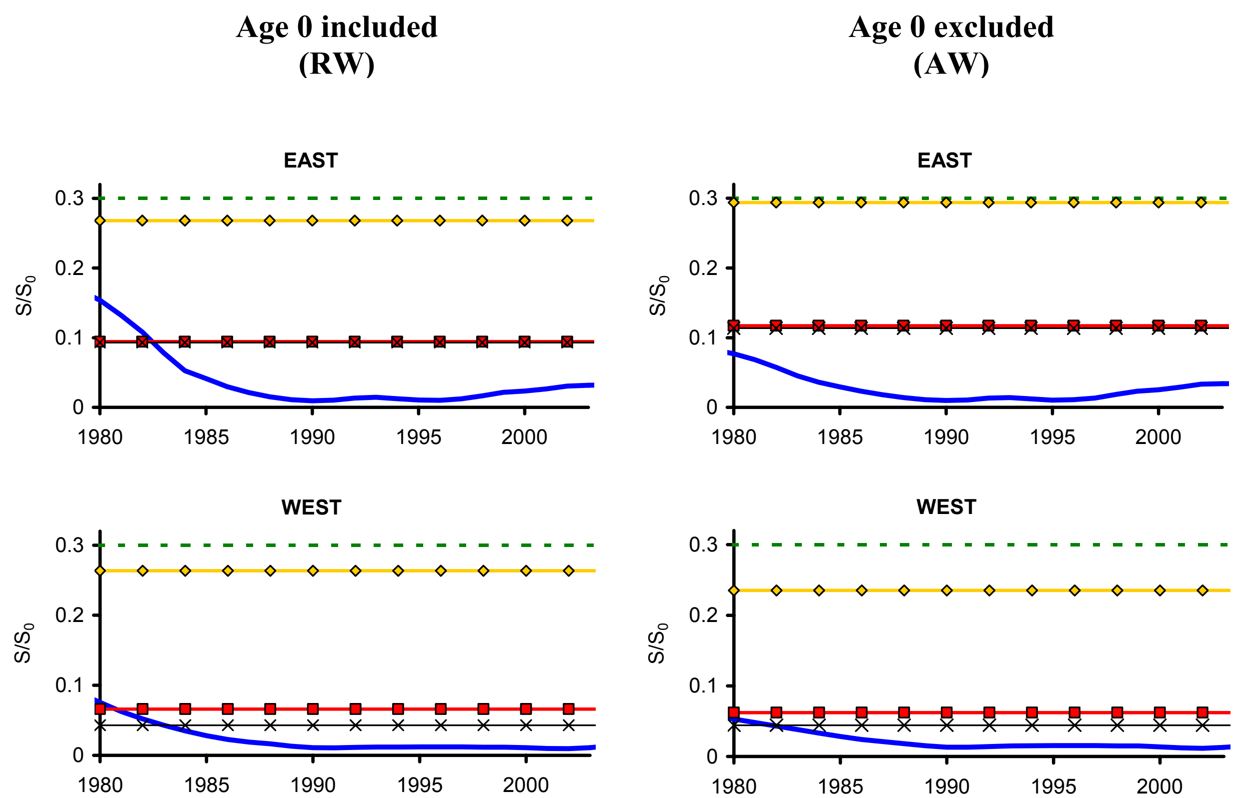


Figure 9. Trends in spawning potential relative to virgin levels (S/S_0, blue curve) compared with four benchmarks based on recent recruitment estimates: $S_{30\%}$ = dashed green line; S_{MSY}\{equal proportions\} = gold diamonds; S_{MSY}\{40% reduced shrimp\} = red circles; and S_{MSY}\{current shrimp\} = black x's. The panels on the left give the results obtained when age 0 fish are modeled explicitly, with the implication that accounting for the bycatch of age 0 is more important than accounting for post-settlement density-dependent processes. The panels on the right give the results obtained when age 0 fish are *not* modeled explicitly, with the implication that accounting for the bycatch of age 0 is less important than accounting for post-settlement density-dependent processes.

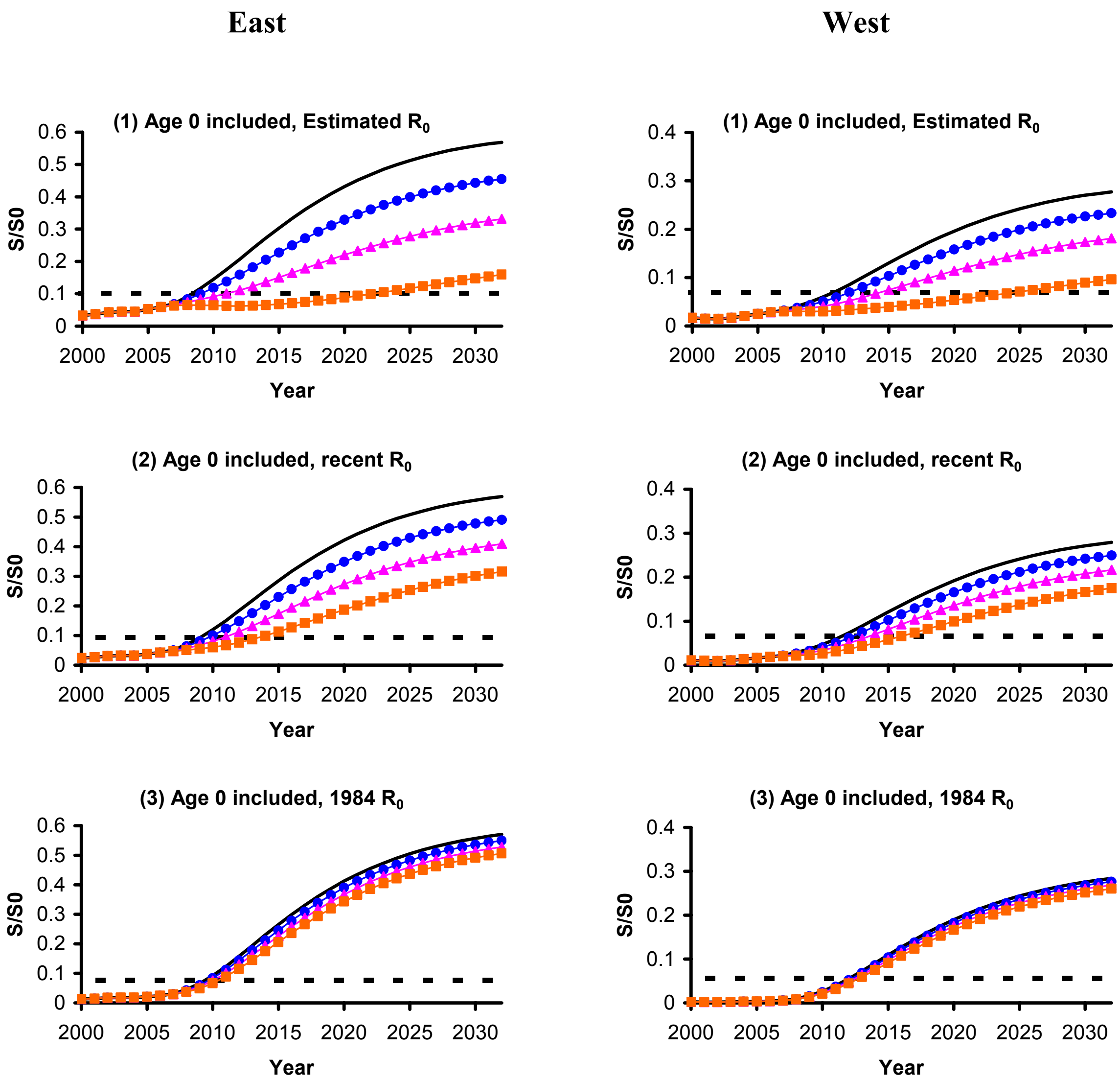


Figure 10. Projections of relative spawning potential based on Model A (age 0 included, long-time series) under various levels of TAC: 0 mp (black line), 3 mp (blue circles), 6 mp (pink triangles), and 9 mp (orange squares). Offshore shrimp trawling effort is reduced by 40% beginning in 2007. Future recruitment is assumed to follow a Beverton-Holt relationship with a steepness of 0.974 and values of R_0 set equal to (1) the model A estimates of R_0, (2) the average of the recruitment estimates from model A for 1984-2003 and (3) the model B (short-time series) estimates of R_0.

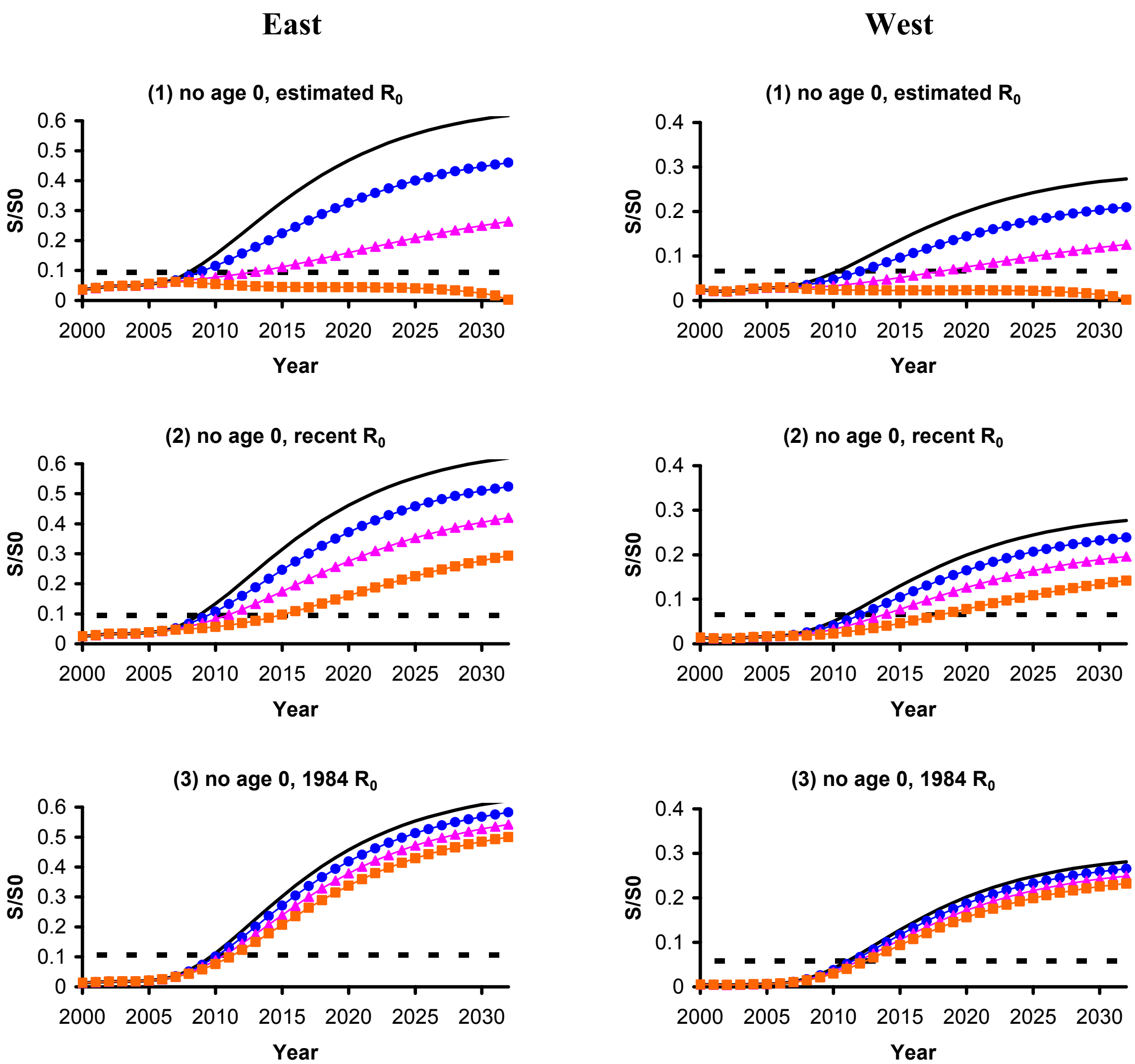


Figure 11. Projections of relative spawning potential based on the age-1 counterpart to model A, which does not include age 0, under various levels of TAC: 0 mp (black line), 3 mp (blue circles), 6 mp (pink triangles), and 9 mp (orange squares). Offshore shrimp trawling effort is reduced by 40% beginning in 2007. Future recruitment is assumed to follow a Beverton-Holt relationship with a steepness of 0.974 and values of R_0 set equal to (1) the model A estimates of R_0, (2) the average of the recruitment estimates from model A for 1984-2003 and (3) the model B (short-time series) estimates of R_0.

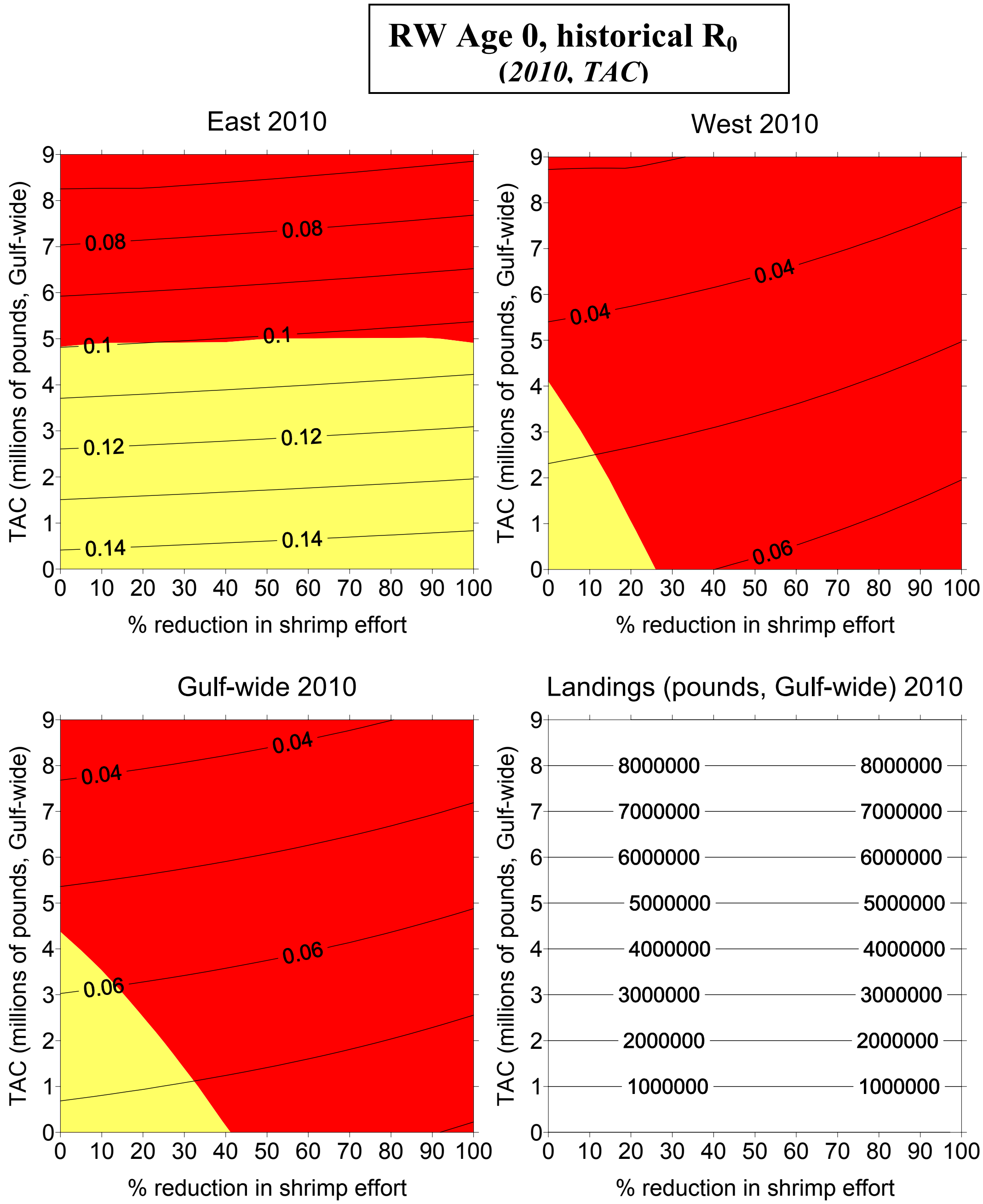


Figure 12a. Isopleths of spawning potential in the year 2010 relative to virgin levels (S_{2010}/S_0) obtained from the RW base model (age 0 included) when the model estimates of R_0 are used. The horizontal axis refers to the projected percent reduction in shrimp effort from current (2001-2003) levels (current levels are estimated to have been reduced by 11% in the east and 17% in the west relative to the estimates for 1984-89). The vertical axis refers to the projected Gulf-wide TAC. The color shades on the graphs represent different levels of spawning potential relative to MSY levels (S_{2010}/S_{MSY}), where MSY is conditioned on the indicated reduction in shrimp effort. Red represents $S_{2010}/S_{MSY}<1$, yellow represents $1 \leq S_{2010}/S_{MSY}<4$, and green represents $S_{2010}/S_{MSY} > 4$.

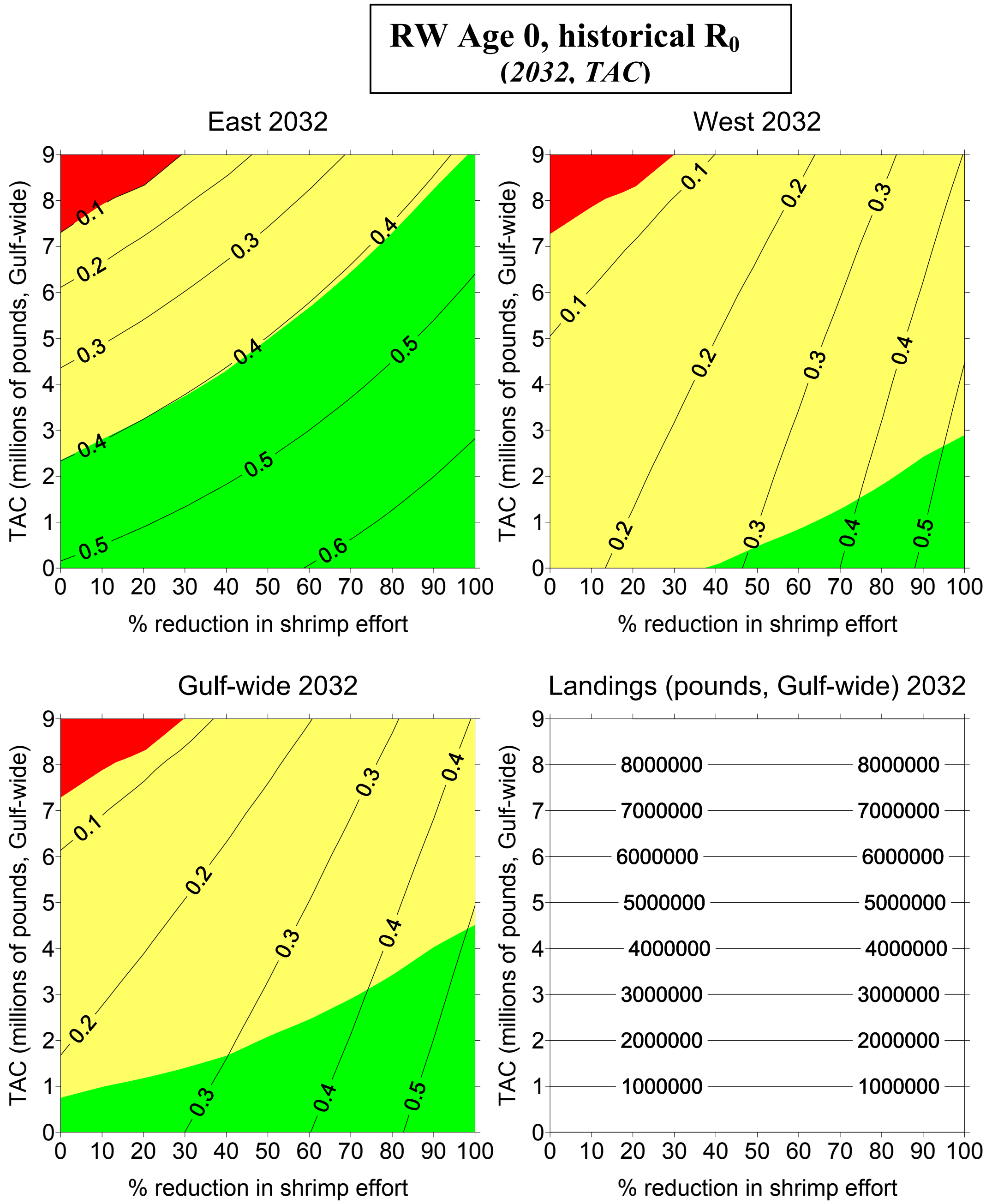


Figure 12b. Isopleths of spawning potential in the year 2032 relative to virgin levels (S_{2032}/S_0) obtained from the RW base model (age 0 included) when the model estimates of R_0 are used. The horizontal axis refers to the projected percent reduction in shrimp effort from current (2001-2003) levels (current levels are estimated to have been reduced by 11% in the east and 17% in the west relative to the estimates for 1984-89). The vertical axis refers to the projected Gulf-wide TAC. The color shades on the graphs represent different levels of spawning potential relative to MSY levels (S_{2032}/S_{MSY}), where MSY is conditioned on the indicated reduction in shrimp effort. Red represents $S_{2032}/S_{MSY}<1$, yellow represents $1 \leq S_{2032}/S_{MSY}<4$, and green represents $S_{2032}/S_{MSY} > 4$.

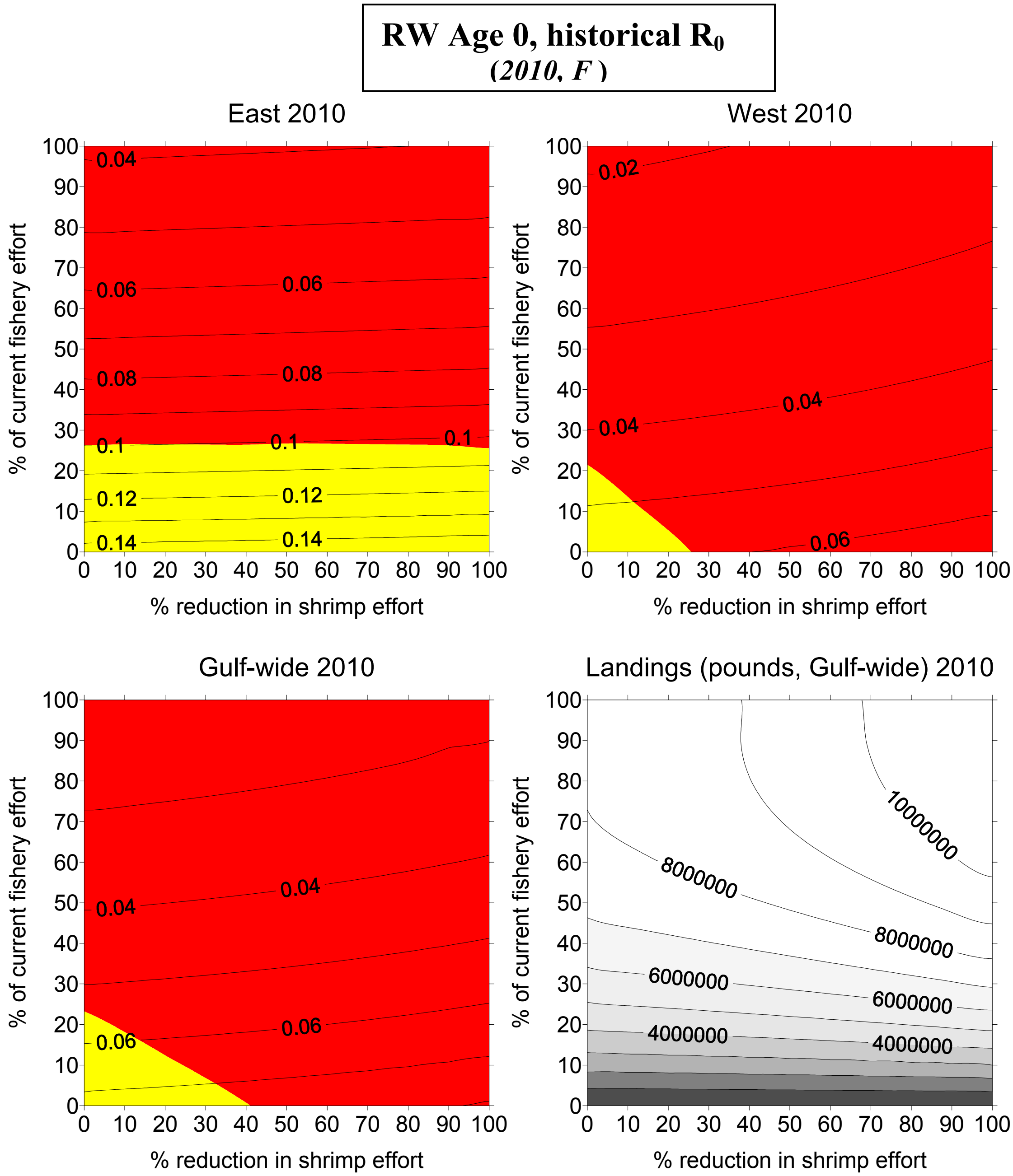


Figure 12c. Isopleths of spawning potential in the year 2010 relative to virgin levels (S_{2010}/S_0) obtained from the RW base model (age 0 included) when the model estimates of R_0 are used. The horizontal axis refers to the projected percent reduction in shrimp effort from current (2001-2003) levels (current levels are estimated to have been reduced by 11% in the east and 17% in the west relative to the estimates for 1984-89). The vertical axis refers to the fishing mortality rate (as a percent of current levels). The color shades on the graphs represent different levels of spawning potential relative to MSY levels (S_{2010}/S_{MSY}), where MSY is conditioned on the indicated reduction in shrimp effort. Red represents $S_{2010}/S_{MSY}<1$, yellow represents $1 \leq S_{2010}/S_{MSY}<4$, and green represents $S_{2010}/S_{MSY} > 4$.

RW Age 0, historical R_0
(2032, F)

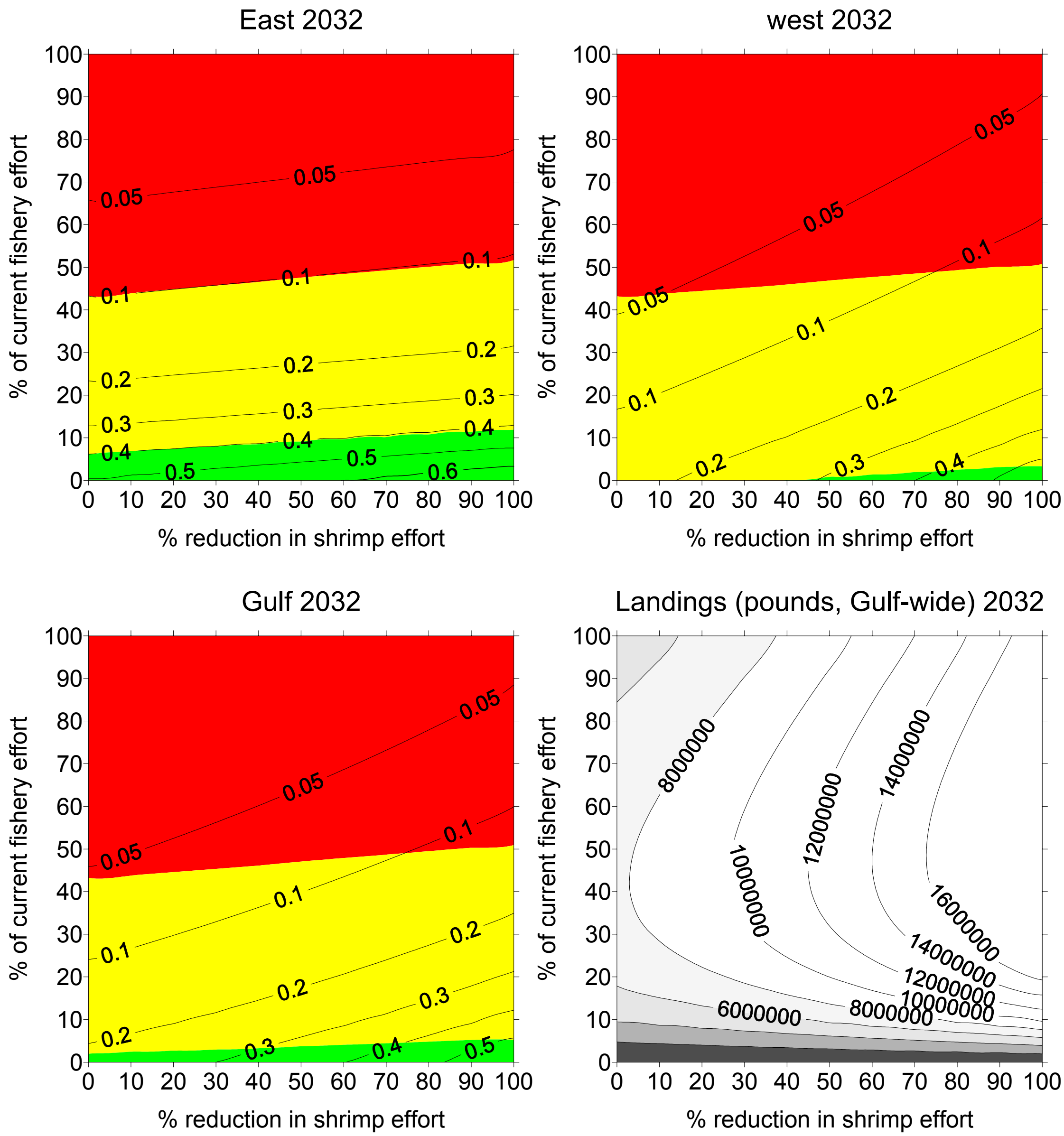


Figure 12d. Isopleths of spawning potential in the year 2032 relative to virgin levels (S_{2032}/S_0) obtained from the RW base model (age 0 included) when the model estimates of R_0 are used. The horizontal axis refers to the projected percent reduction in shrimp effort from current (2001-2003) levels (current levels are estimated to have been reduced by 11% in the east and 17% in the west relative to the estimates for 1984-89). The vertical axis refers to the fishing mortality rate (as a percent of current levels). The color shades on the graphs represent different levels of spawning potential relative to MSY levels (S_{2032}/S_{MSY}), where MSY is conditioned on the indicated reduction in shrimp effort. Red represents $S_{2032}/S_{MSY}<1$, yellow represents $1 \leq S_{2032}/S_{MSY}<4$, and green represents $S_{2032}/S_{MSY} > 4$.

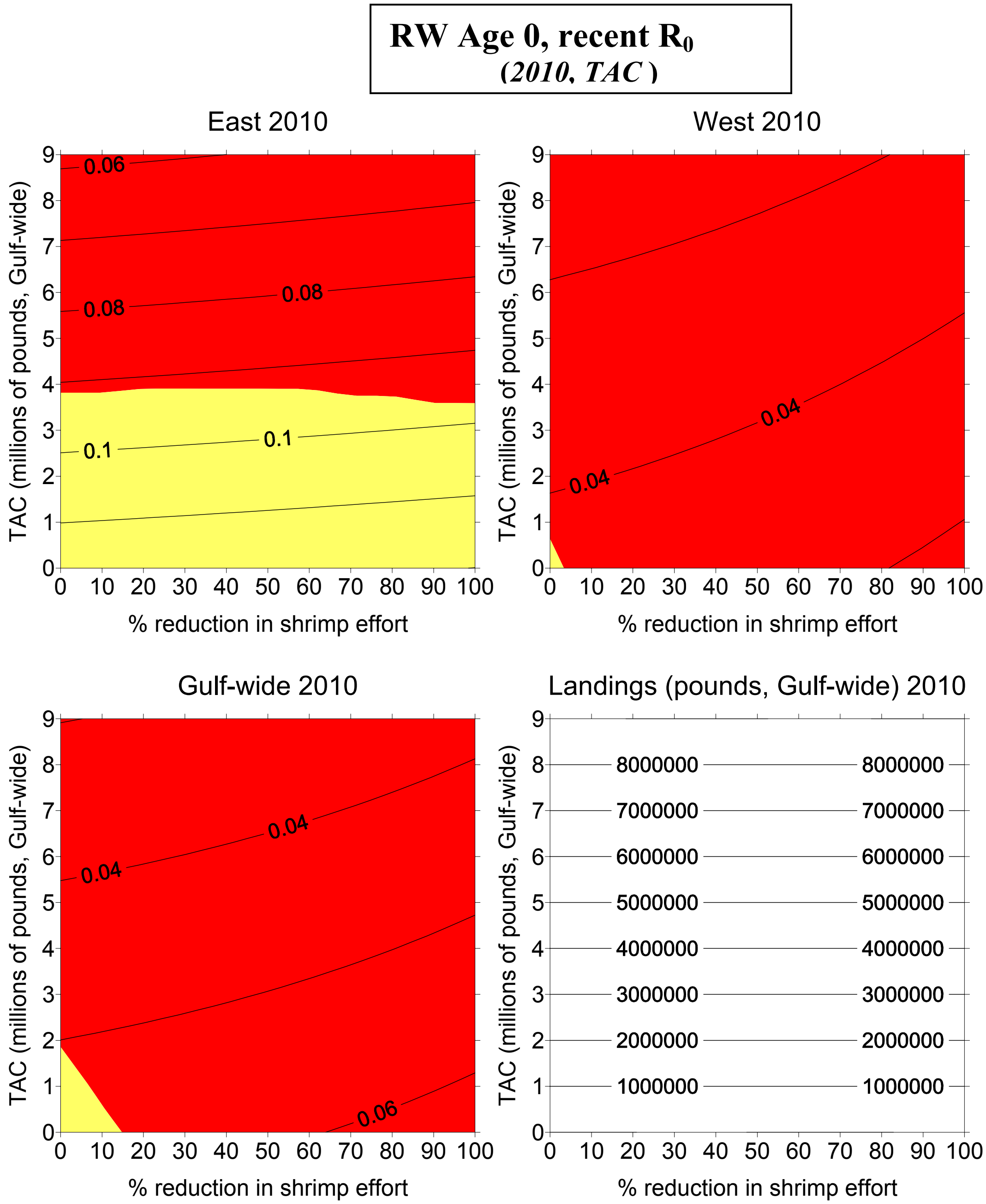


Figure 13a. Isopleths of spawning potential in the year 2010 relative to virgin levels (S_{2010}/S_0) obtained from the RW base model (age 0 included) when R_0 is set to the average of the recruitment estimates from 1984-2003. The horizontal axis refers to the projected percent reduction in shrimp effort from current (2001-2003) levels (current levels are estimated to have been reduced by 11% in the east and 17% in the west relative to the estimates for 1984-89). The vertical axis refers to the projected Gulf-wide TAC. The color shades represent different levels of spawning potential relative to MSY levels (S_{2010}/S_{MSY}), where MSY is conditioned on the indicated reduction in shrimp effort. Red represents $S_{2010}/S_{MSY}<1$, yellow represents $1 \leq S_{2010}/S_{MSY}<4$, and green represents $S_{2010}/S_{MSY} > 4$.

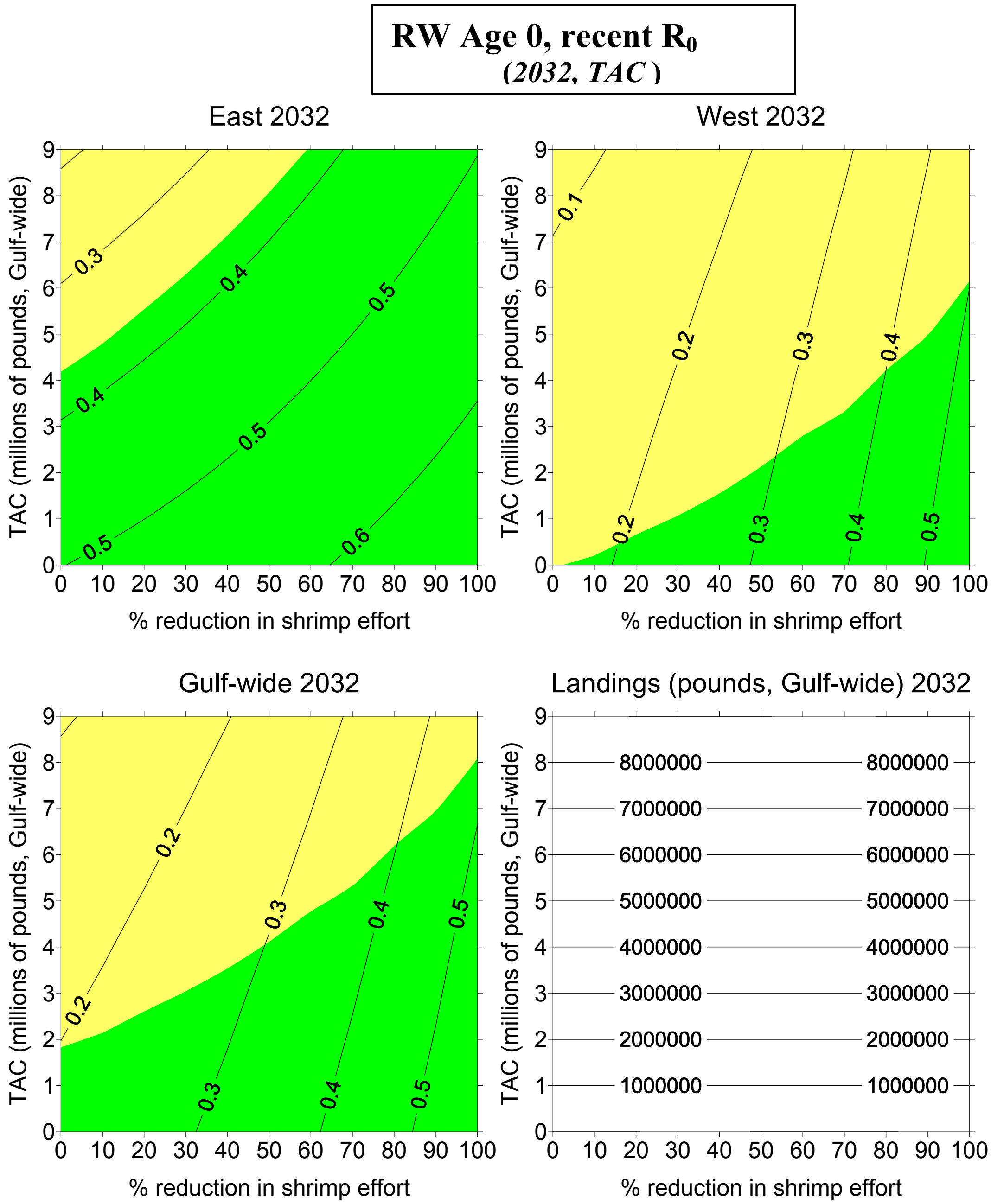


Figure 13b. Isopleths of spawning potential in the year 2032 relative to virgin levels (S_{2032}/S_0) obtained from the RW base model (age 0 included) when R_0 is set to the average of the recruitment estimates from 1984-2003. The horizontal axis refers to the projected percent reduction in shrimp effort from current (2001-2003) levels (current levels are estimated to have been reduced by 11% in the east and 17% in the west relative to the estimates for 1984-89). The vertical axis refers to the projected Gulf-wide TAC. The color shades represent different levels of spawning potential relative to MSY levels (S_{2032}/S_{MSY}), where MSY is conditioned on the indicated reduction in shrimp effort. Red represents $S_{2032}/S_{MSY}<1$, yellow represents $1 \leq S_{2032}/S_{MSY}<4$, and green represents $S_{2032}/S_{MSY} > 4$.

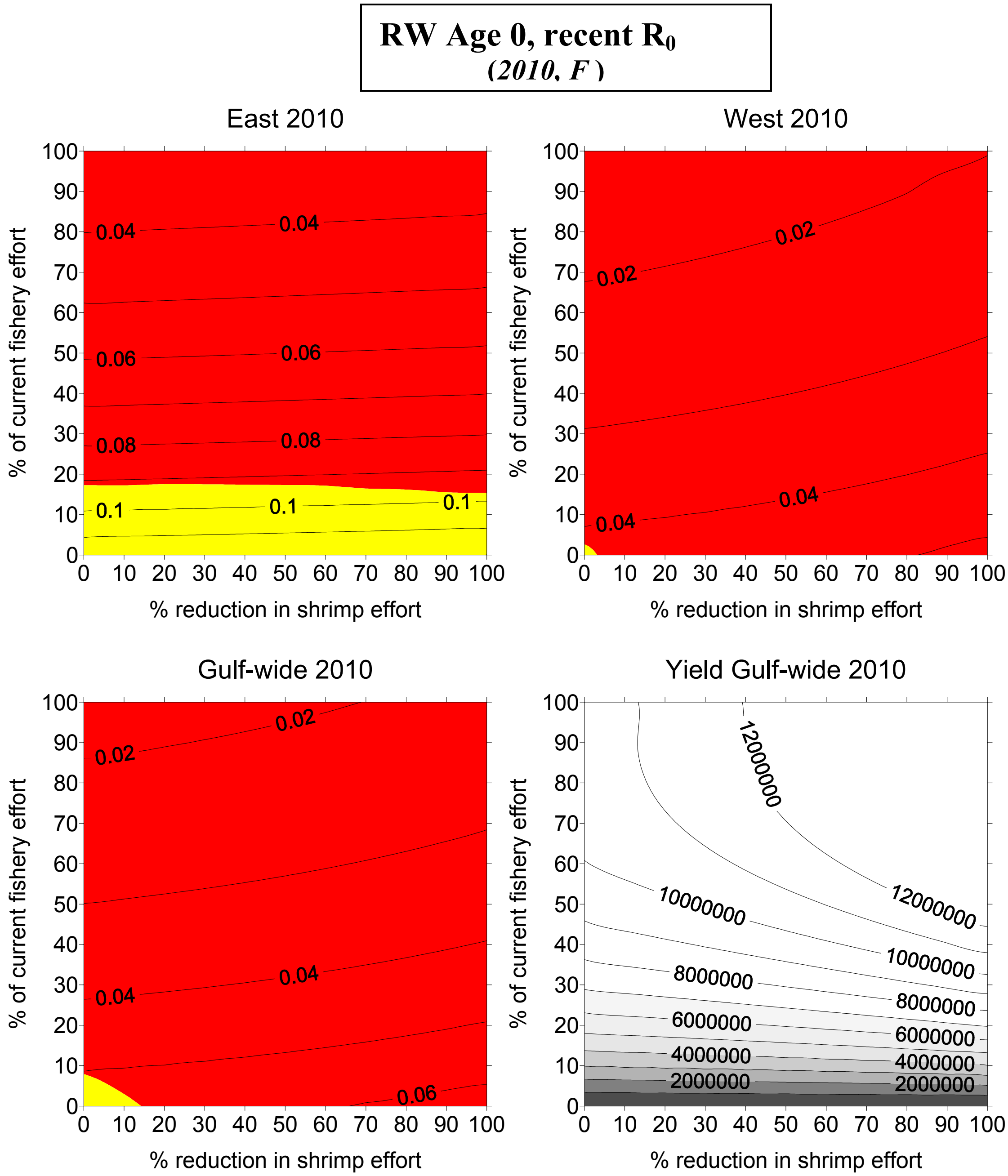


Figure 13c. Isopleths of spawning potential in the year 2010 relative to virgin levels (S_{2010}/S_0) obtained from the RW base model (age 0 included) when R_0 is set to the average of the recruitment estimates from 1984-2003. The horizontal axis refers to the projected percent reduction in shrimp effort from current (2001-2003) levels (current levels are estimated to have been reduced by 11% in the east and 17% in the west relative to the estimates for 1984-89). The vertical axis refers to the fishing mortality rate (as a percent of current levels). Colors represent spawning potential relative to MSY levels (S_{2010}/S_{MSY}), where MSY is conditioned on the indicated reduction in shrimp effort. Red represents $S_{2010}/S_{MSY}<1$, yellow represents $1 \leq S_{2010}/S_{MSY}<4$, and green represents $S_{2010}/S_{MSY} > 4$.

RW Age 0, recent R_0

(2032, F)

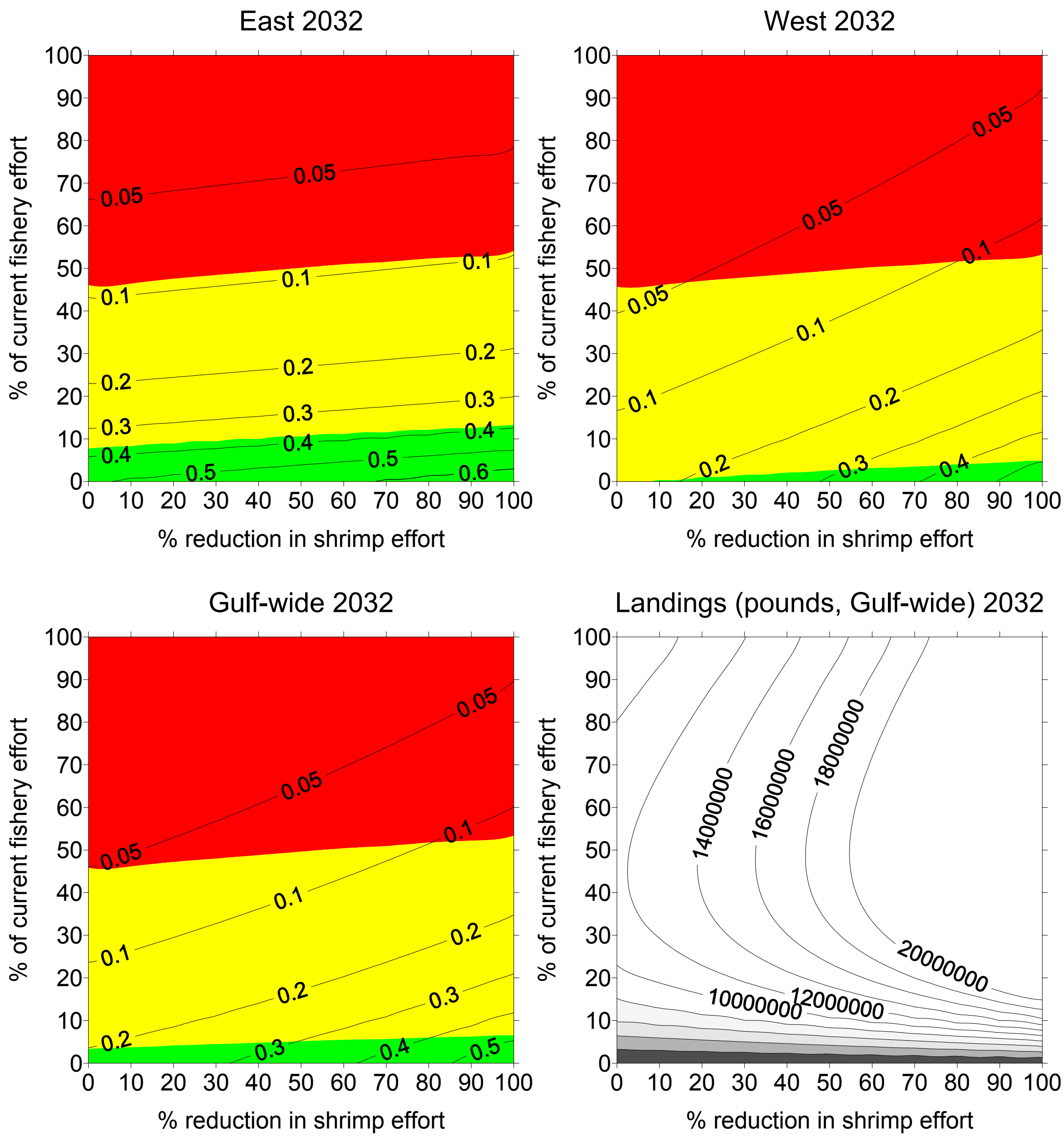


Figure 13d. Isopleths of spawning potential in the year 2032 relative to virgin levels (S_{2032}/S_0) obtained from the RW base model (age 0 included) when R_0 is set to the average of the recruitment estimates from 1984-2003. The horizontal axis refers to the projected percent reduction in shrimp effort from current (2001-2003) levels (current levels are estimated to have been reduced by 11% in the east and 17% in the west relative to the estimates for 1984-89). The vertical axis refers to the fishing mortality rate (as a percent of current levels). Colors represent spawning potential relative to MSY levels (S_{2032}/S_{MSY}), where MSY is conditioned on the indicated reduction in shrimp effort. Red represents $S_{2032}/S_{MSY}<1$, yellow represents $1 \leq S_{2032}/S_{MSY}<4$, and green represents $S_{2032}/S_{MSY} > 4$.

AW Age 1, historical R_0
(2010, TAC)

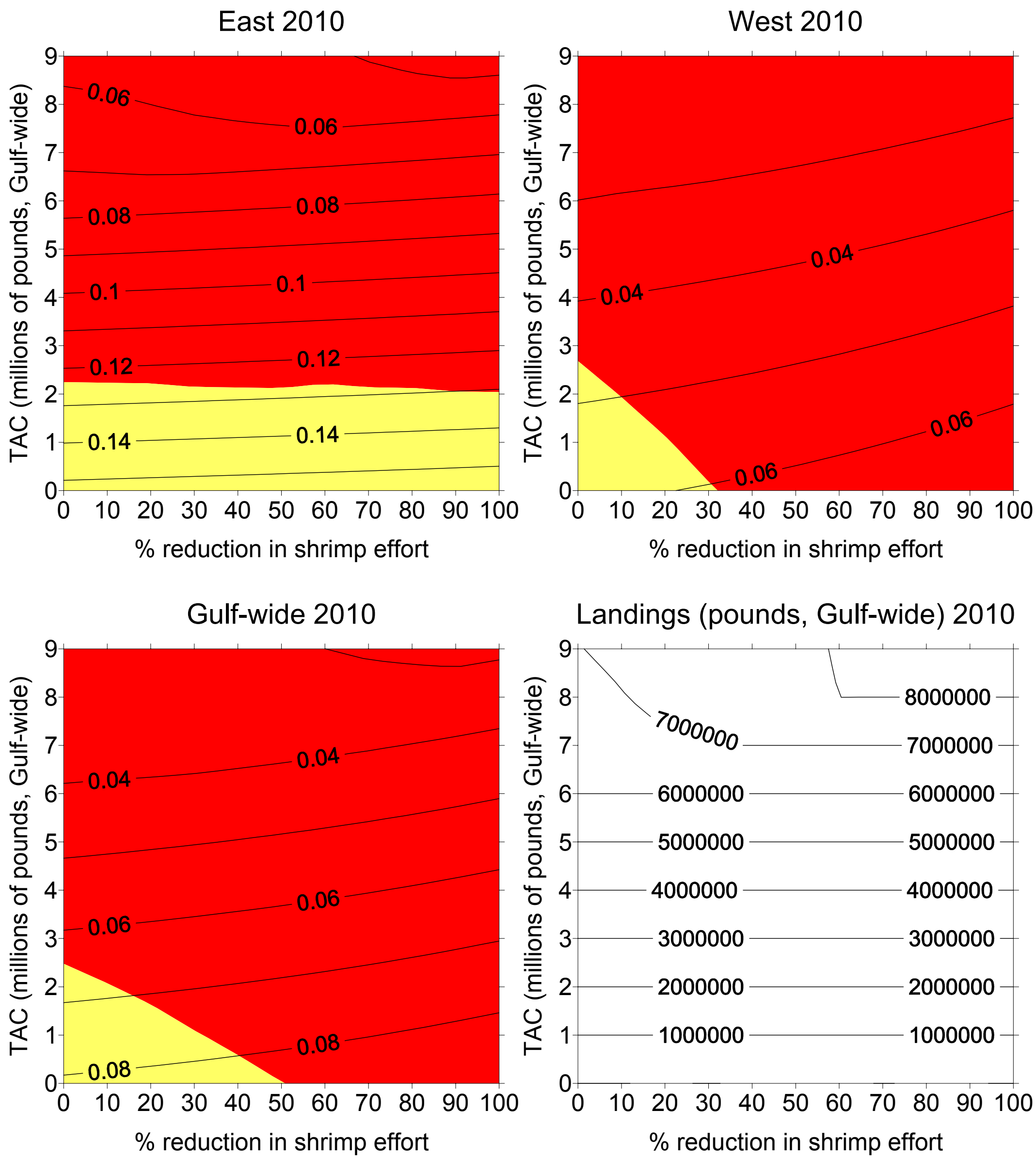


Figure 14a. Isopleths of spawning potential in the year 2010 relative to virgin levels (S_{2010}/S_0) obtained from the AW base model (no age 0) when the model estimates of R_0 are used. The horizontal axis refers to the projected percent reduction in shrimp effort from current (2001-2003) levels (current levels are estimated to have been reduced by 11% in the east and 17% in the west relative to the estimates for 1984-89). The vertical axis refers to the projected Gulf-wide TAC. Colors represent S_{2010}/S_{MSY}, where MSY is conditioned on the indicated reduction in shrimp effort. Red represents $S_{2010}/S_{MSY}<1$, yellow represents $1 \leq S_{2010}/S_{MSY}<4$, and green $S_{2010}/S_{MSY} > 4$. Landings isopleths that do not coincide with the TAC labels indicate that the particular TAC could not be sustained.

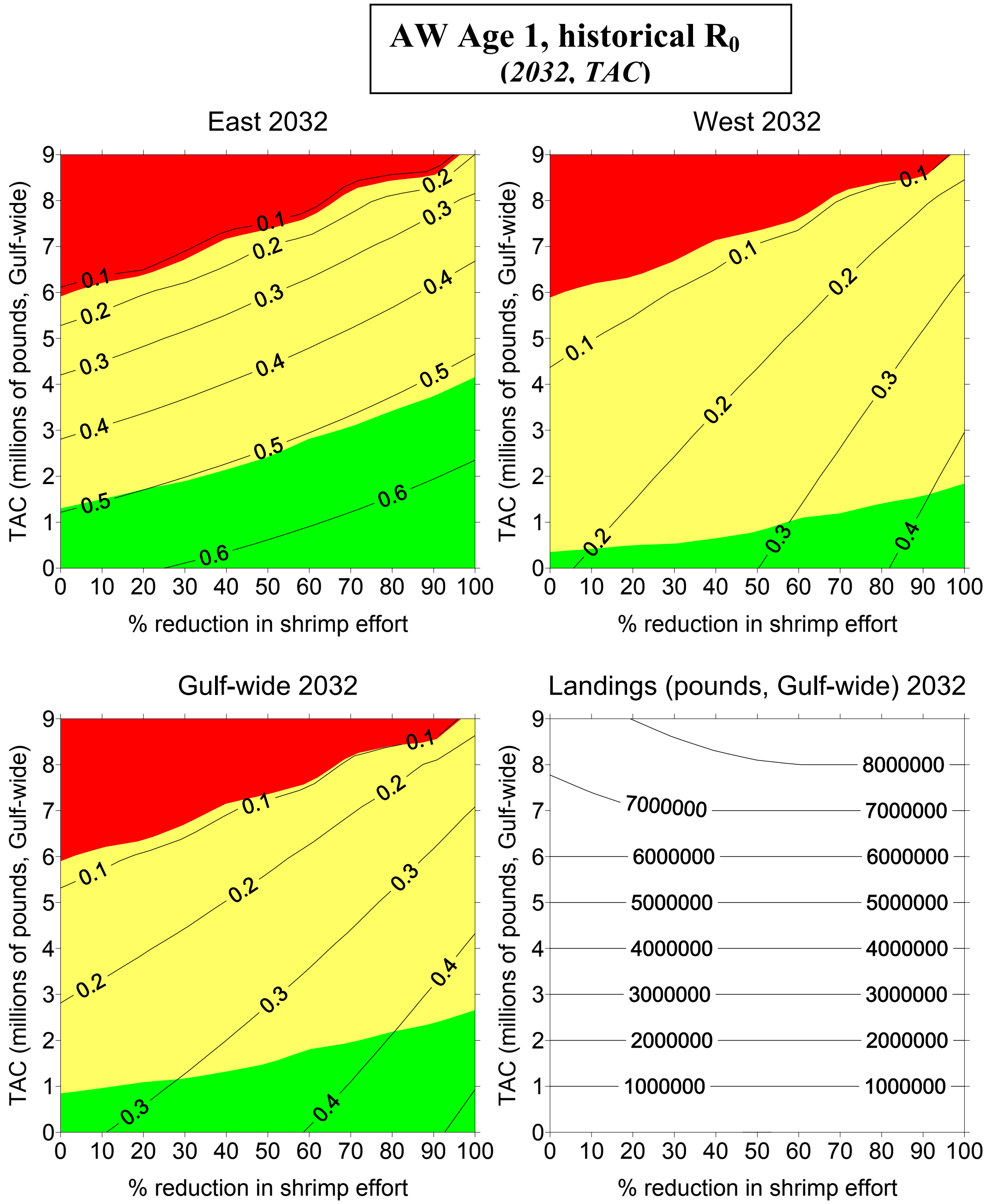


Figure 14b. Isopleths of spawning potential in the year 2032 relative to virgin levels (S_{2032}/S_0) obtained from the AW base model (no age 0) when the model estimates of R_0 are used. The horizontal axis refers to the projected percent reduction in shrimp effort from current (2001-2003) levels (current levels are estimated to have been reduced by 11% in the east and 17% in the west relative to the estimates for 1984-89). The vertical axis refers to the projected Gulf-wide TAC. Colors represent S_{2032}/S_{MSY}, where MSY is conditioned on the indicated reduction in shrimp effort. Red represents $S_{2032}/S_{MSY}<1$, yellow represents $1 \leq S_{2032}/S_{MSY}<4$, and green $S_{2032}/S_{MSY} > 4$. Landings isopleths that do not coincide with the TAC labels indicate that the particular TAC could not be sustained.

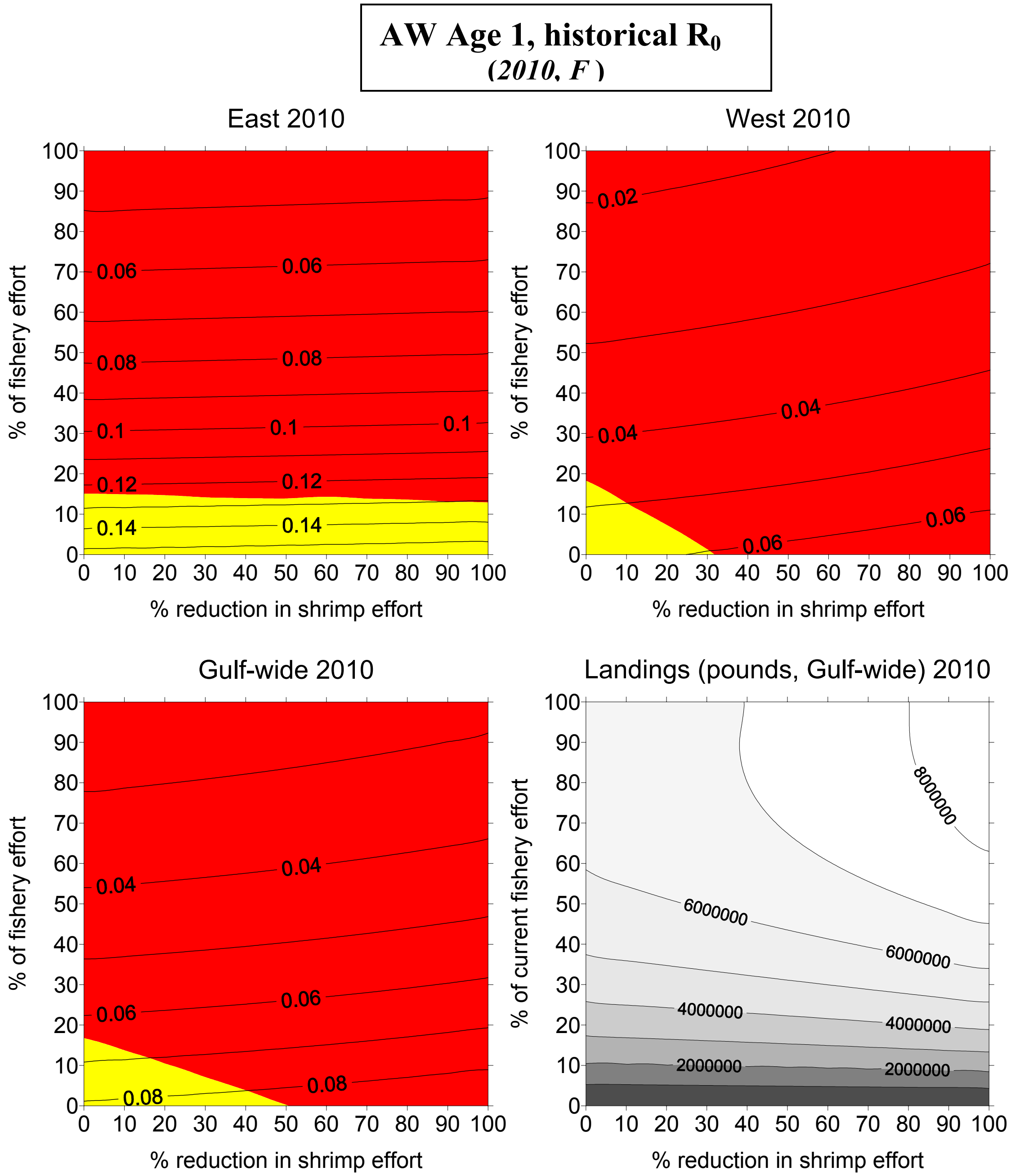


Figure 14c. Isopleths of spawning potential in the year 2010 relative to virgin levels (S_{2010}/S_0) obtained from the AW base model (no age 0) when the model estimates of R_0 are used. The horizontal axis refers to the projected percent reduction in shrimp effort from current (2001-2003) levels (current levels are estimated to have been reduced by 11% in the east and 17% in the west relative to the estimates for 1984-89). The vertical axis refers to the fishing mortality rate (as a percent of current levels). The color shades on the graphs represent different levels of spawning potential relative to MSY levels (S_{2010}/S_{MSY}), where MSY is conditioned on the indicated reduction in shrimp effort. Red represents $S_{2010}/S_{MSY}<1$, yellow represents $1 \leq S_{2010}/S_{MSY}<4$, and green represents $S_{2010}/S_{MSY} > 4$.

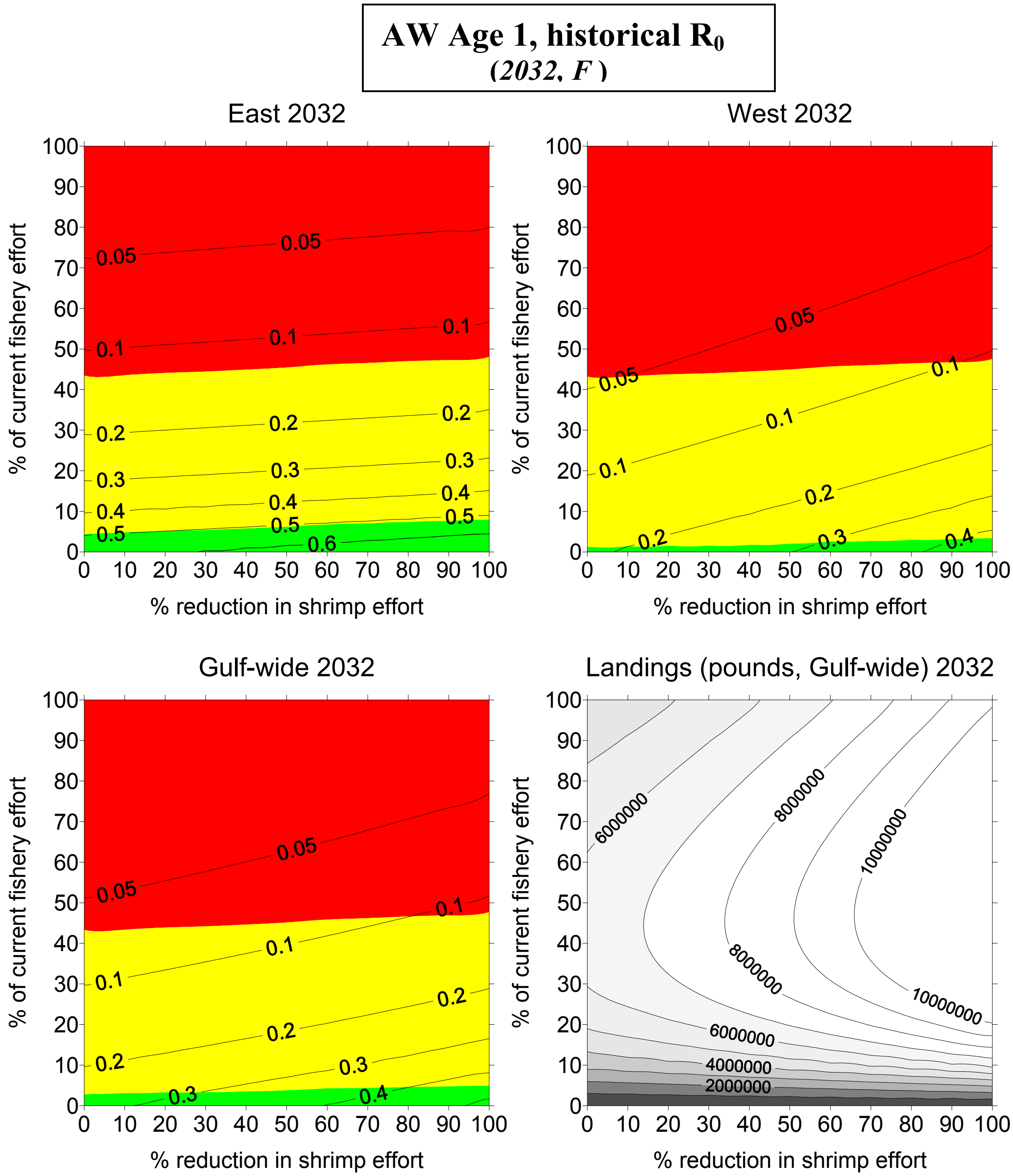


Figure 14d. Isopleths of spawning potential in the year 2032 relative to virgin levels (S_{2032}/S_0) obtained from the AW base model (no age 0) when the model estimates of R_0 are used. The horizontal axis refers to the projected percent reduction in shrimp effort from current (2001-2003) levels (current levels are estimated to have been reduced by 11% in the east and 17% in the west relative to the estimates for 1984-89). The vertical axis refers to the fishing mortality rate (as a percent of current levels). Colors represent spawning potential relative to MSY levels (S_{2032}/S_{MSY}), where MSY is conditioned on the indicated reduction in shrimp effort. Red represents $S_{2032}/S_{MSY}<1$, yellow represents $1 \leq S_{2032}/S_{MSY}<4$, and green represents $S_{2032}/S_{MSY} > 4$.

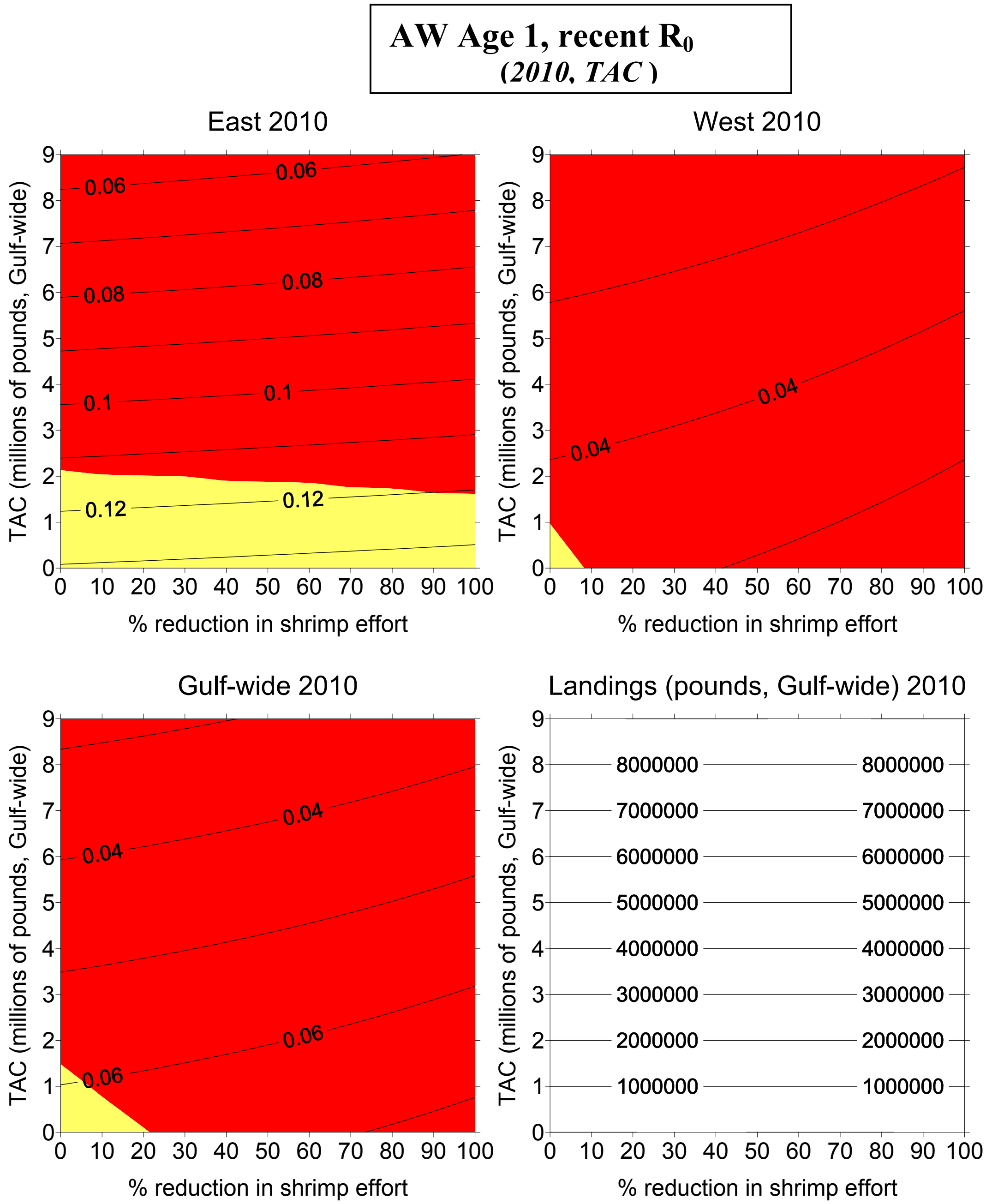


Figure 15a. Isopleths of spawning potential in the year 2010 relative to virgin levels (S_{2010}/S_0) obtained from the AW base model (no age 0) when R_0 is set to the average of the recruitment estimates from 1984-2003. The horizontal axis refers to the projected percent reduction in shrimp effort from current (2001-2003) levels (current levels are estimated to have been reduced by 11% in the east and 17% in the west relative to the estimates for 1984-89). The vertical axis refers to the projected Gulf-wide TAC. The color shades on the graphs represent different levels of spawning potential relative to MSY levels (S_{2010}/S_{MSY}), where MSY is conditioned on the indicated reduction in shrimp effort. Red represents $S_{2010}/S_{MSY}<1$, yellow represents $1 \leq S_{2010}/S_{MSY}<4$, and green represents $S_{2010}/S_{MSY} > 4$.

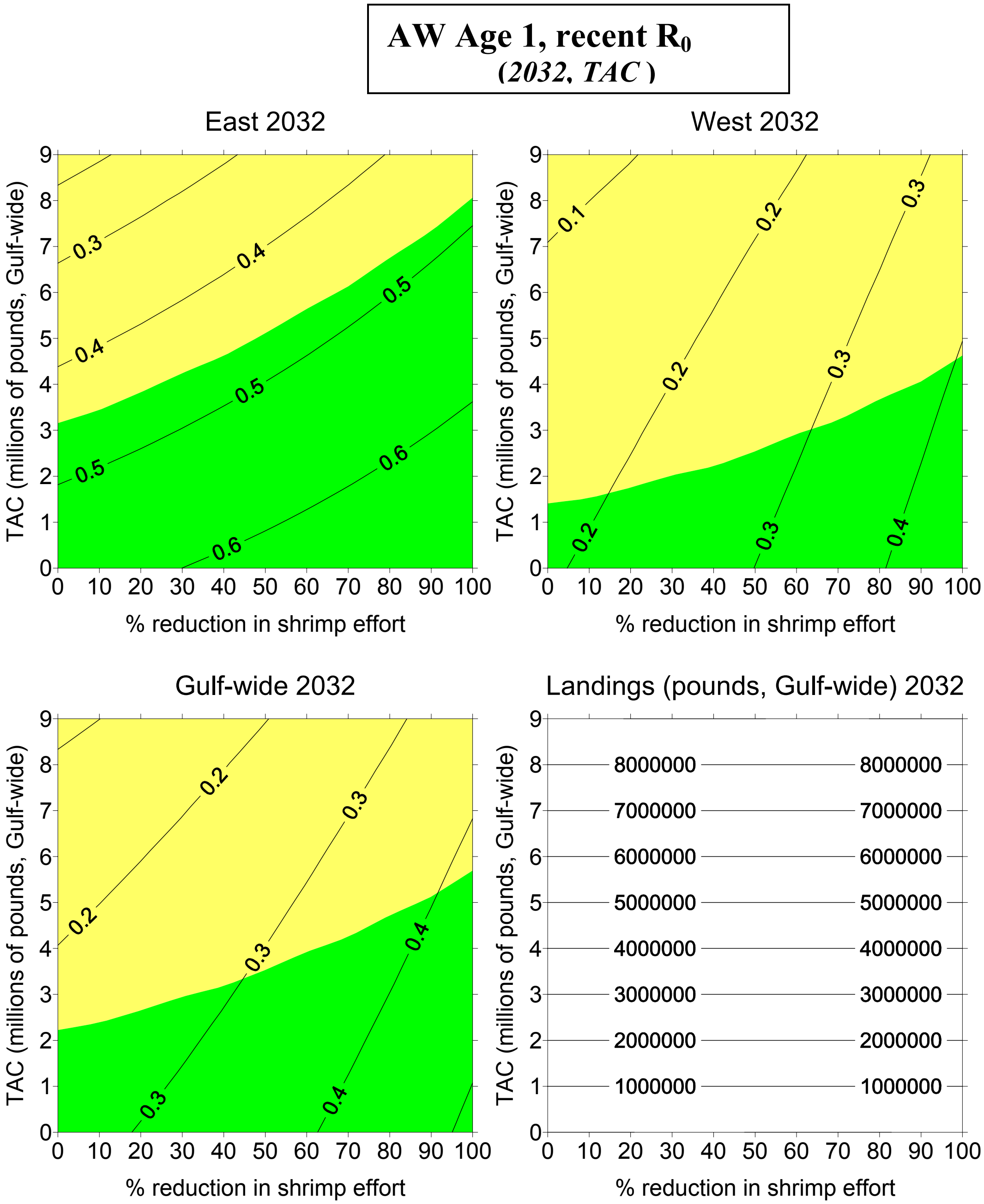


Figure 15b. Isopleths of spawning potential in the year 2032 relative to virgin levels (S_{2032}/S_0) obtained from the AW base model (no age 0) when R_0 is set to the average of the recruitment estimates from 1984-2003. The horizontal axis refers to the projected percent reduction in shrimp effort from current (2001-2003) levels (current levels are estimated to have been reduced by 11% in the east and 17% in the west relative to the estimates for 1984-89). The vertical axis refers to the projected Gulf-wide TAC. The color shades on the graphs represent different levels of spawning potential relative to MSY levels (S_{2032}/S_{MSY}), where MSY is conditioned on the indicated reduction in shrimp effort. Red represents $S_{2032}/S_{MSY}<1$, yellow represents $1 \leq S_{2032}/S_{MSY}<4$, and green represents $S_{2032}/S_{MSY} > 4$.

AW Age 1, recent R_0
(2010, F)

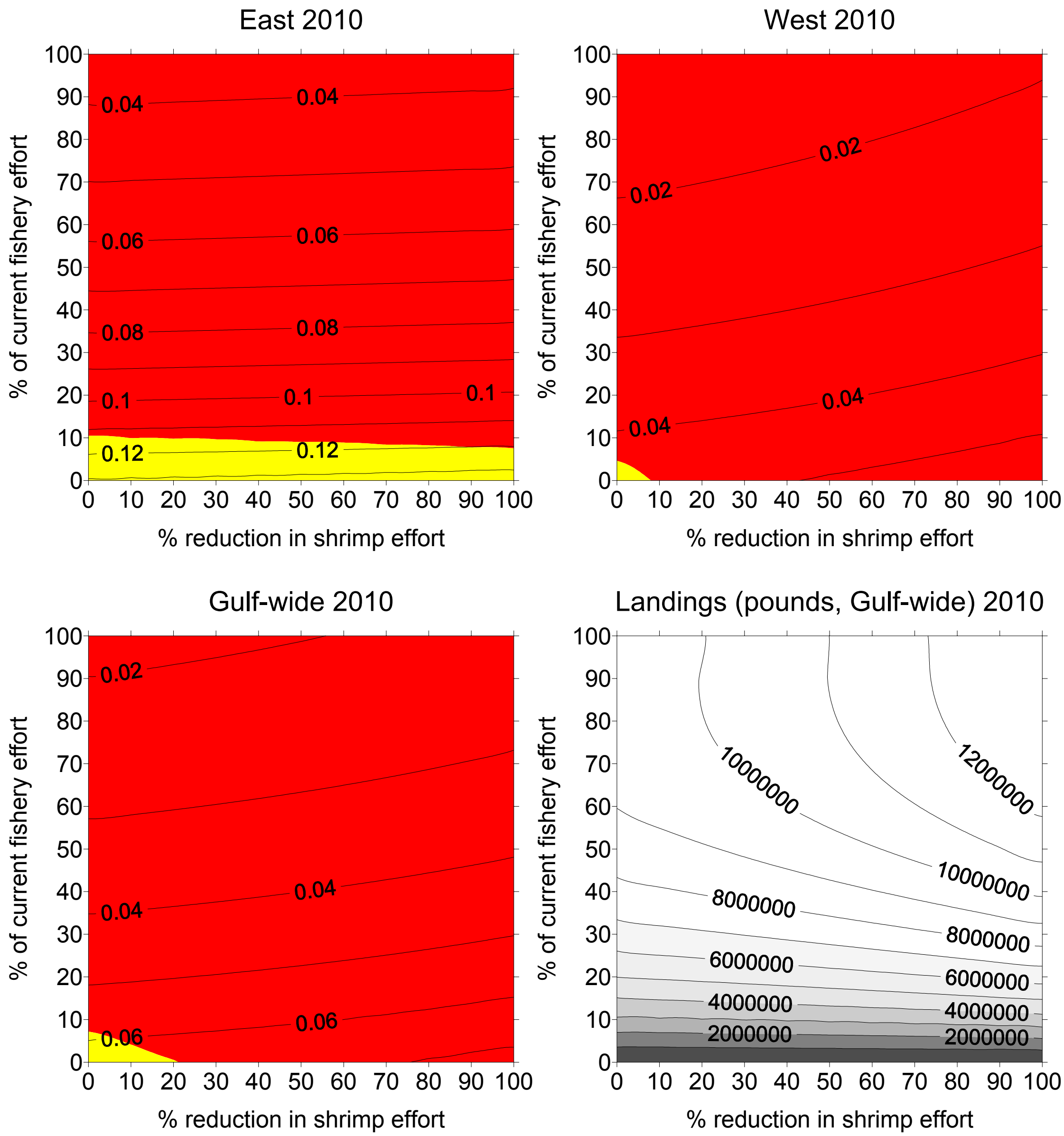


Figure 15c. Isopleths of spawning potential in the year 2010 relative to virgin levels (S_{2010}/S_0) obtained from the AW base model (no age 0) when R_0 is set to the average of the recruitment estimates from 1984-2003. The horizontal axis refers to the projected percent reduction in shrimp effort from current (2001-2003) levels (current levels are estimated to have been reduced by 11% in the east and 17% in the west relative to the estimates for 1984-89). The vertical axis refers to the fishing mortality rate (as a percent of current levels). Colors represent spawning potential relative to MSY levels (S_{2010}/S_{MSY}), where MSY is conditioned on the indicated reduction in shrimp effort. Red represents $S_{2010}/S_{MSY}<1$, yellow represents $1 \leq S_{2010}/S_{MSY}<4$, and green represents $S_{2010}/S_{MSY} > 4$.

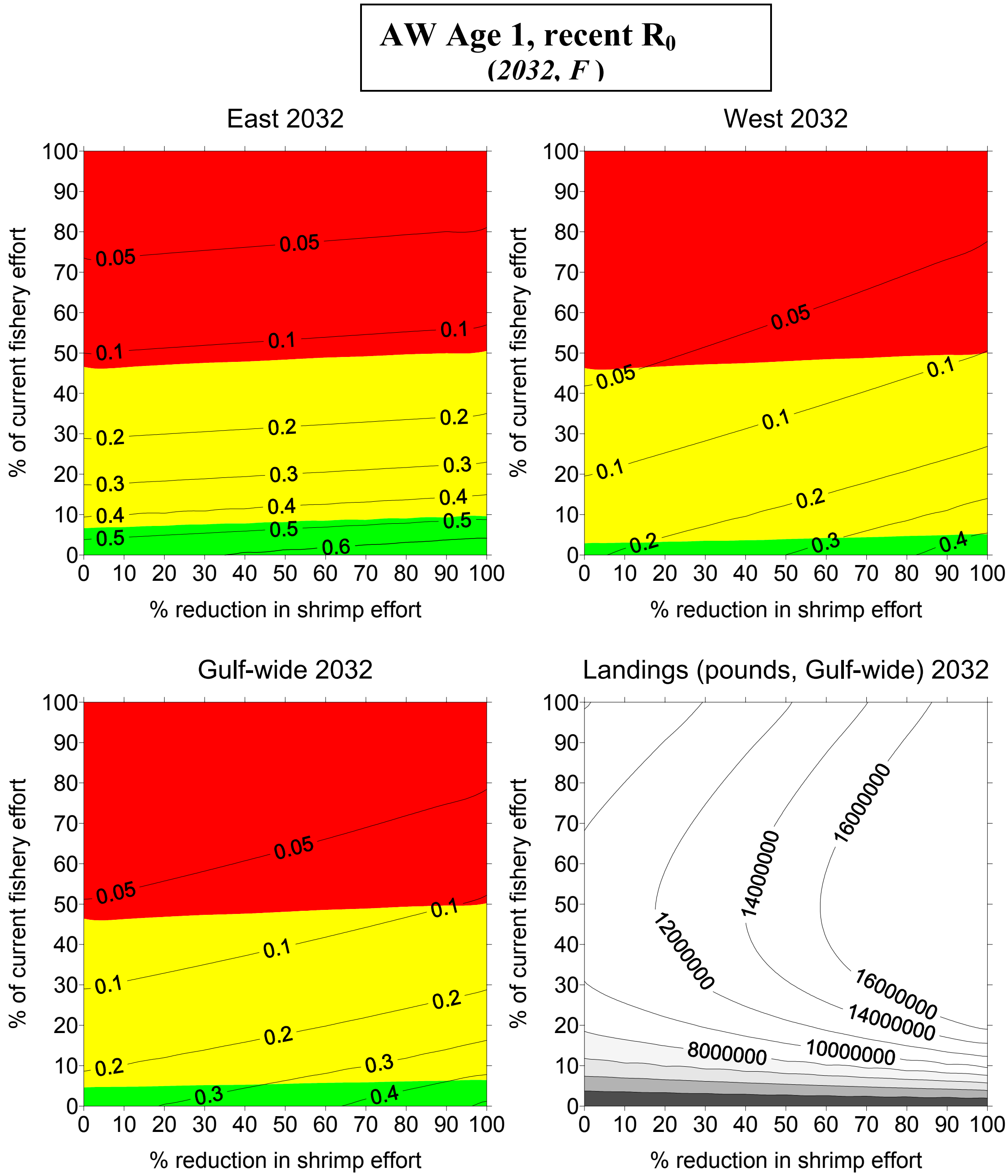


Figure 15d. Isopleths of spawning potential in the year 2032 relative to virgin levels (S_{2032}/S_0) obtained from the AW base model (no age 0) when R_0 is set to the average of the recruitment estimates from 1984-2003. The horizontal axis refers to the projected percent reduction in shrimp effort from current (2001-2003) levels (current levels are estimated to have been reduced by 11% in the east and 17% in the west relative to the estimates for 1984-89). The vertical axis refers to the fishing mortality rate (as a percent of current levels). Colors represent spawning potential relative to MSY levels (S_{2032}/S_{MSY}), where MSY is conditioned on the indicated reduction in shrimp effort. Red represents $S_{2032}/S_{MSY}<1$, yellow represents $1 \leq S_{2032}/S_{MSY}<4$, and green represents $S_{2032}/S_{MSY} > 4$.

APPENDIX – ADDITIONAL DIAGNOSTICS

At the request of the Review Workshop Panel, qq and other diagnostic plots and tables for the RW preferred base model results were prepared to permit evaluation of the appropriateness of the statistical model assumptions used and to examine the relative contribution of age structure vs relative abundance information to the stock status outcomes. These follow

Table AD1. Standard deviation of the standardized residuals for each index and for the observed catch at age. There was a region-specific series for each index (HL=Hand line; LARV=Larval survey; REC=recreational; TRW0=Trawl survey age 0's; TRW1=Trawl survey age 1's; VID=video survey).

Index	**Standard deviation of standardized residuals**
HL-E	0.53
HL-W	0.54
LARV-E	1.98
LARV-W	1.51
REC-E	0.71
REC-W	0.84
TRW0-E	1.47
TRW0-W	1.32
TRW1-E	1.08
TRW1-W	1.08
VID-E	0.81
VID-W	0.80
Catch at age	3.48

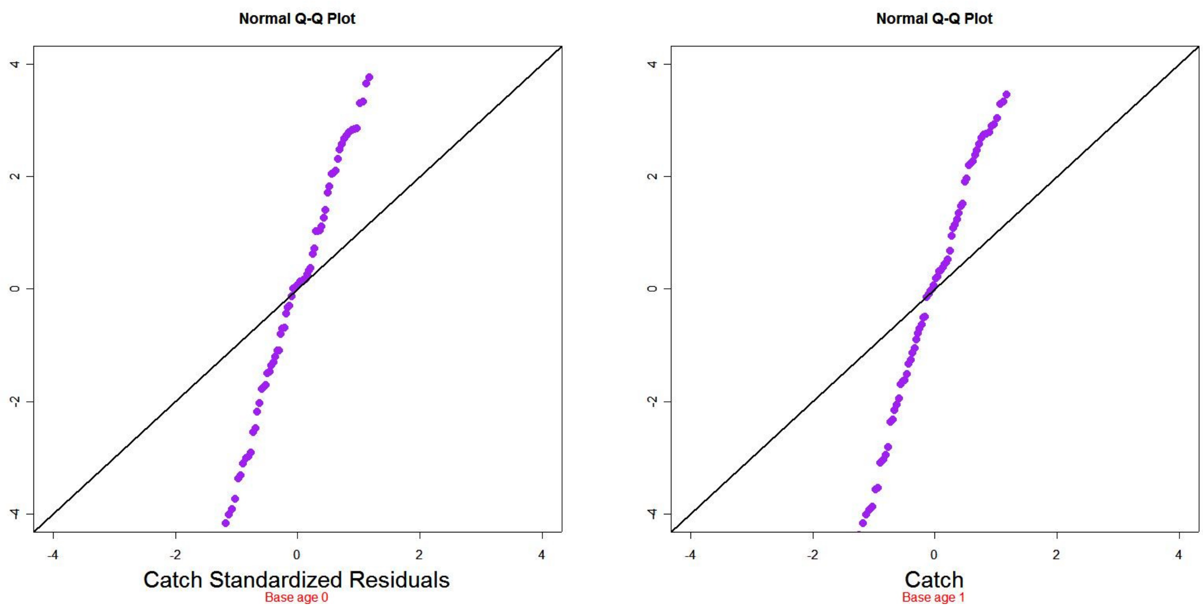


Figure AD1. Q-Q plot of standardized residuals from model fits to observed catch at age (mean = -0.084, standard deviation = 3.48) for models with and without age 0.

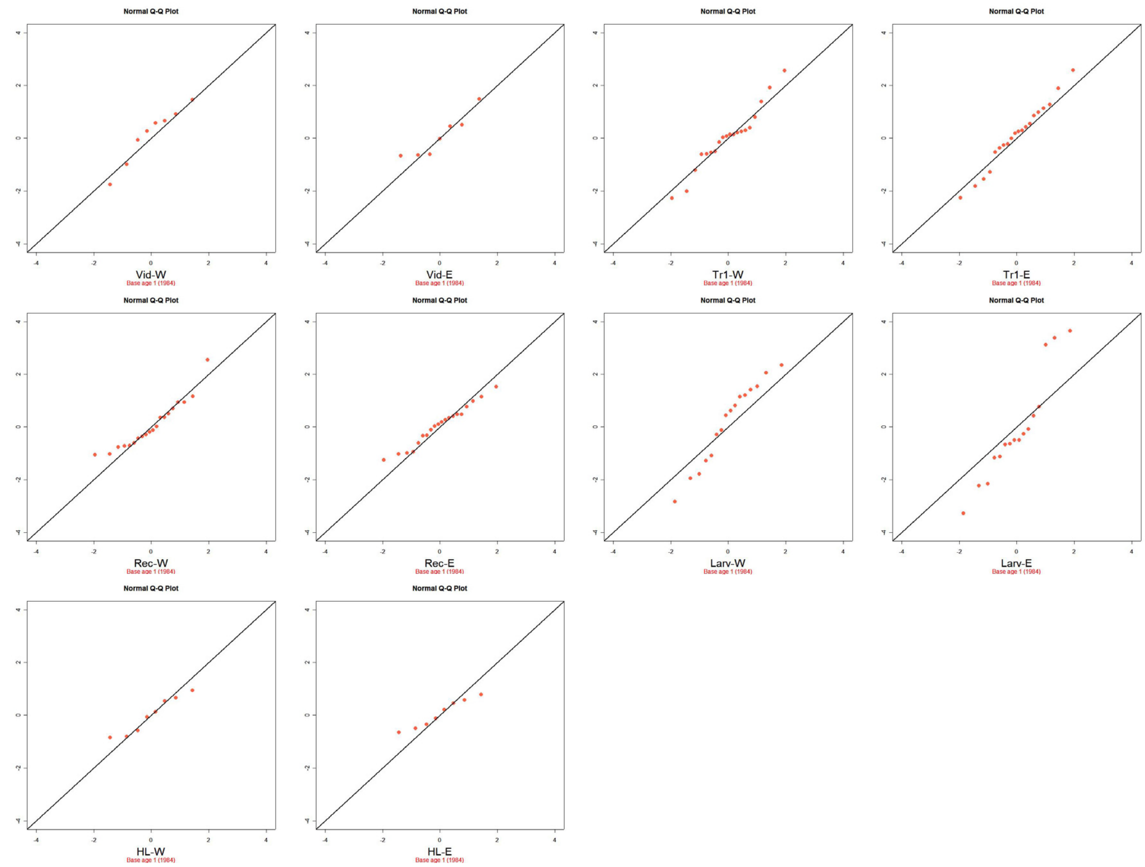


Figure AD2a. Q-Q plot of standardized residuals from model fits to indices of abundance for model based on age-1 model using the short time series (1984-2003).

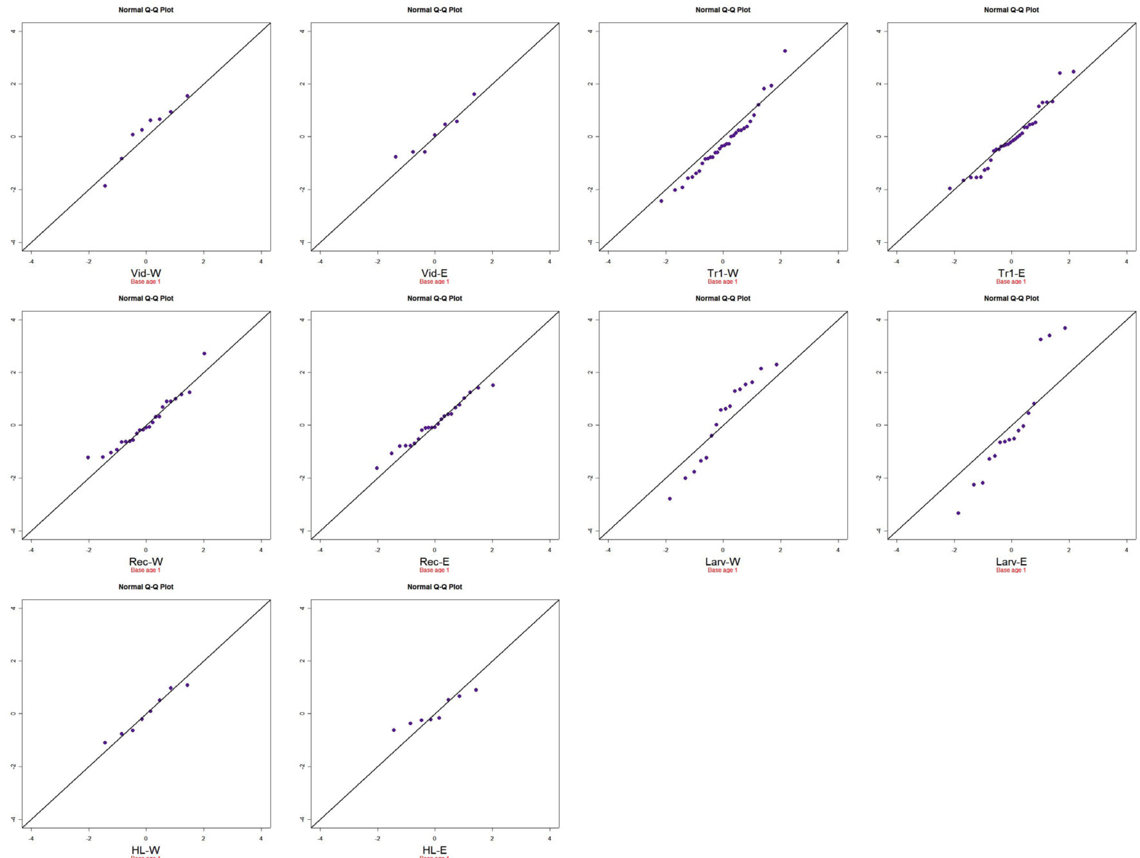


Figure AD2b. Q-Q plot of standardized residuals from model fits to indices of abundance for model based on age-1 model using the long time series (1872-2003).

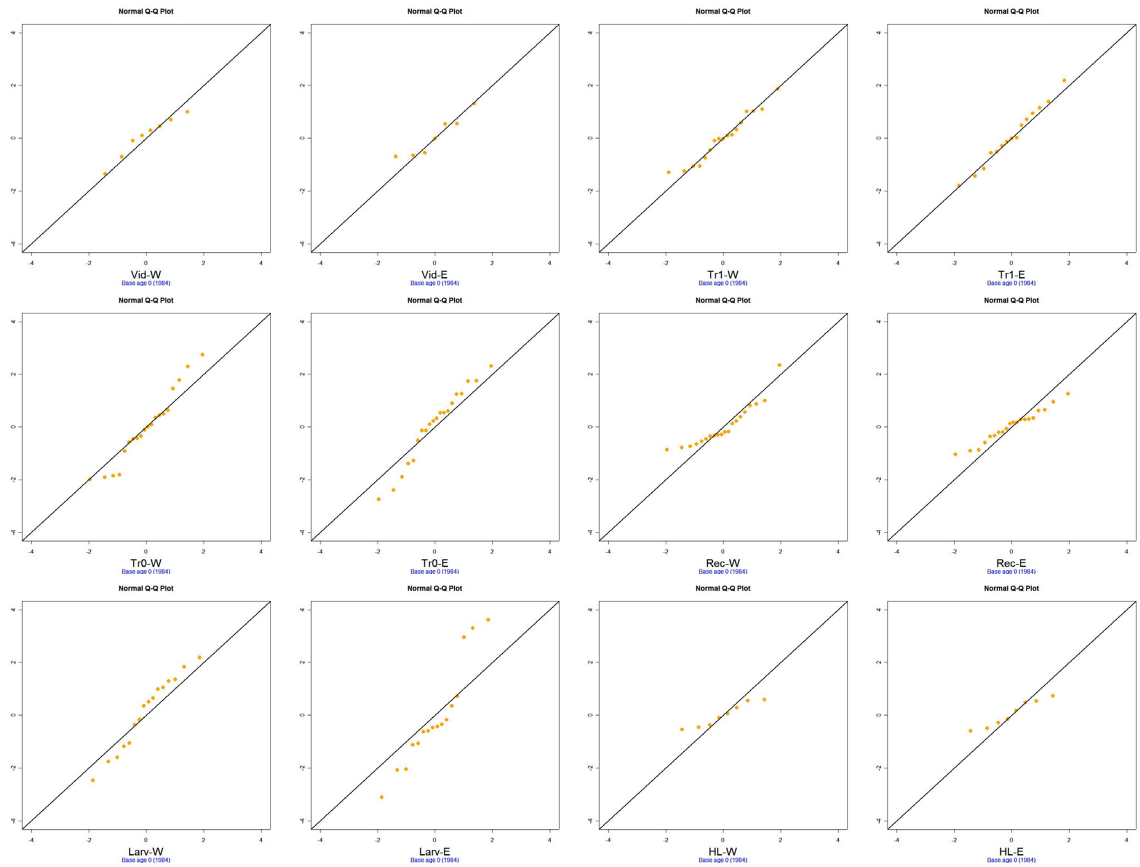


Figure AD2c. Q-Q plot of standardized residuals from model fits to indices of abundance for model based on age-0 model using the short time series (1984-2003).

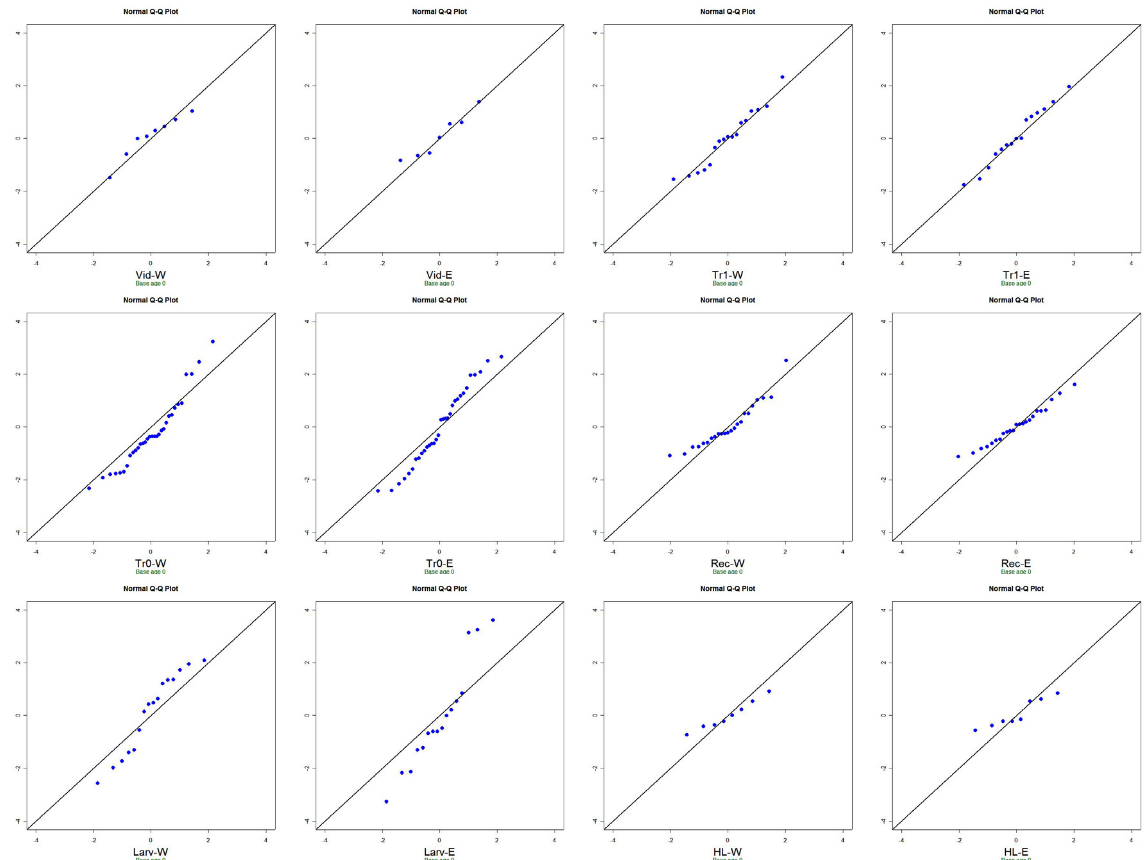
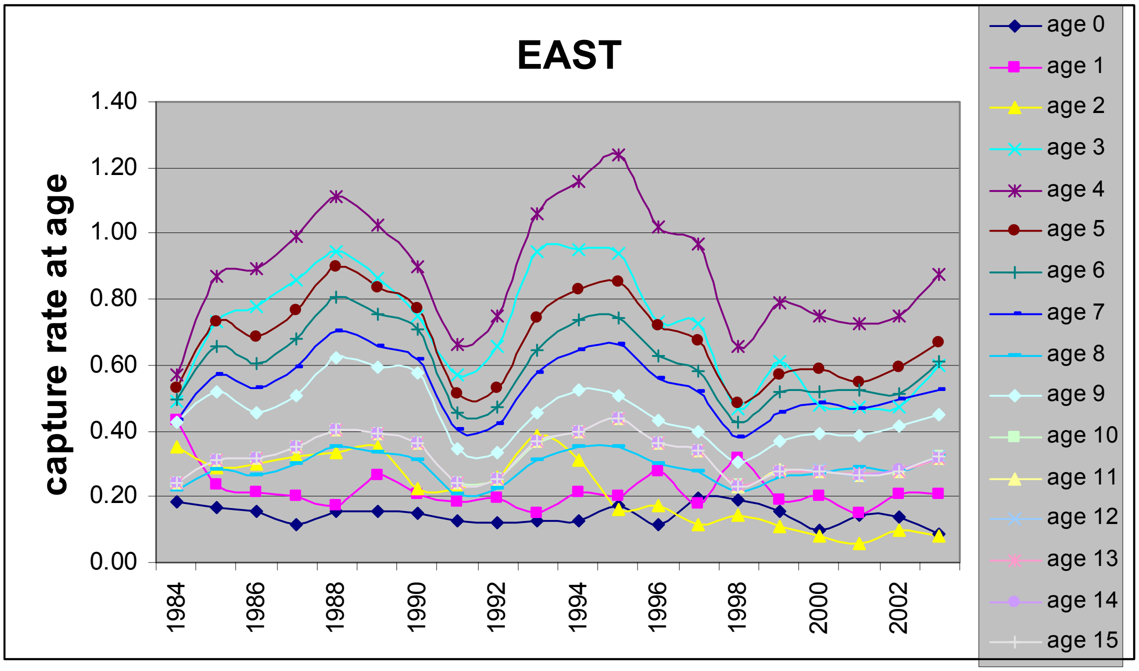


Figure AD2d. Q-Q plot of standardized residuals from model fits to indices of abundance for model based on age-0 model using the long time series (1872-2003).

(a)



(b)

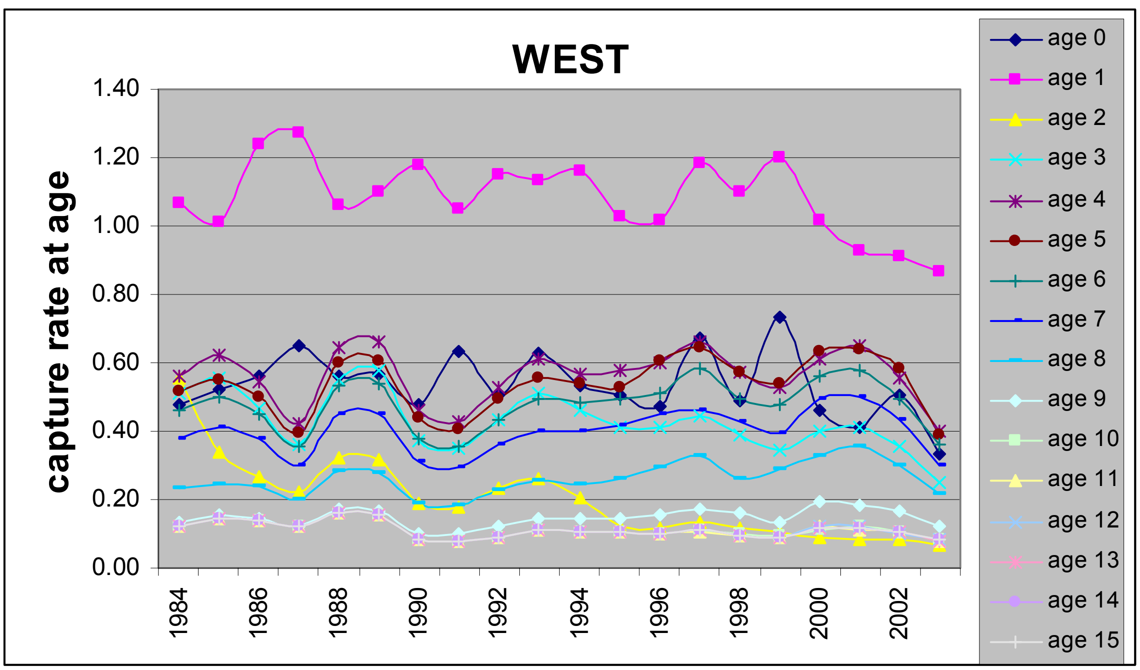
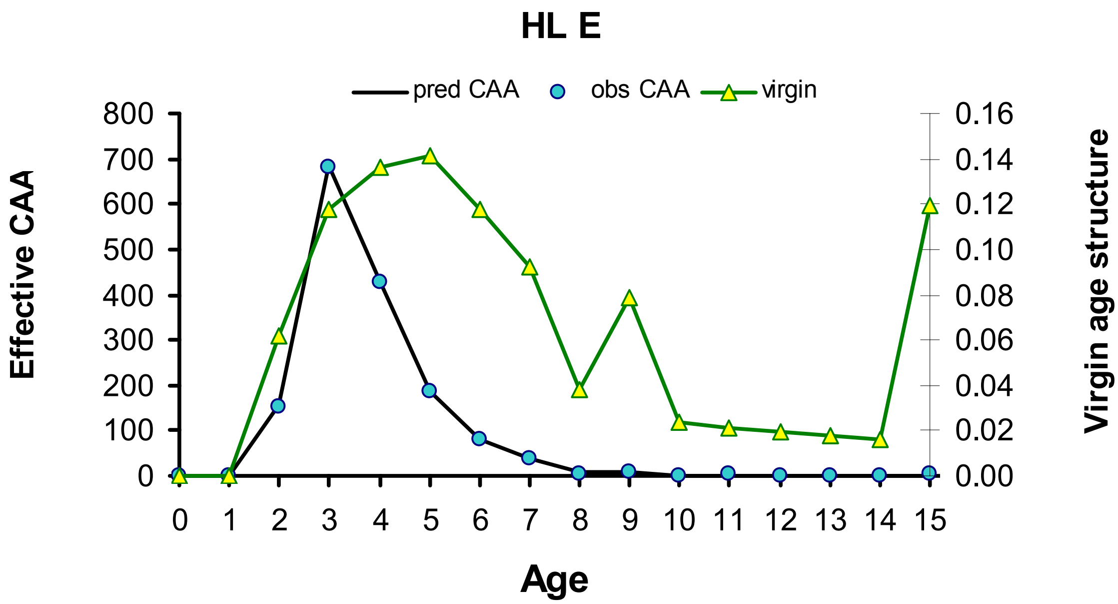


Figure AD3. Capture rate at age in the East (a) and West (b) from 1984-2003. Capture rate reflects the instantaneous rate for fish that were caught (this includes landings as well as discards due to size limits and closed seasons). Age 15 is a plus group.

(a)



(b)

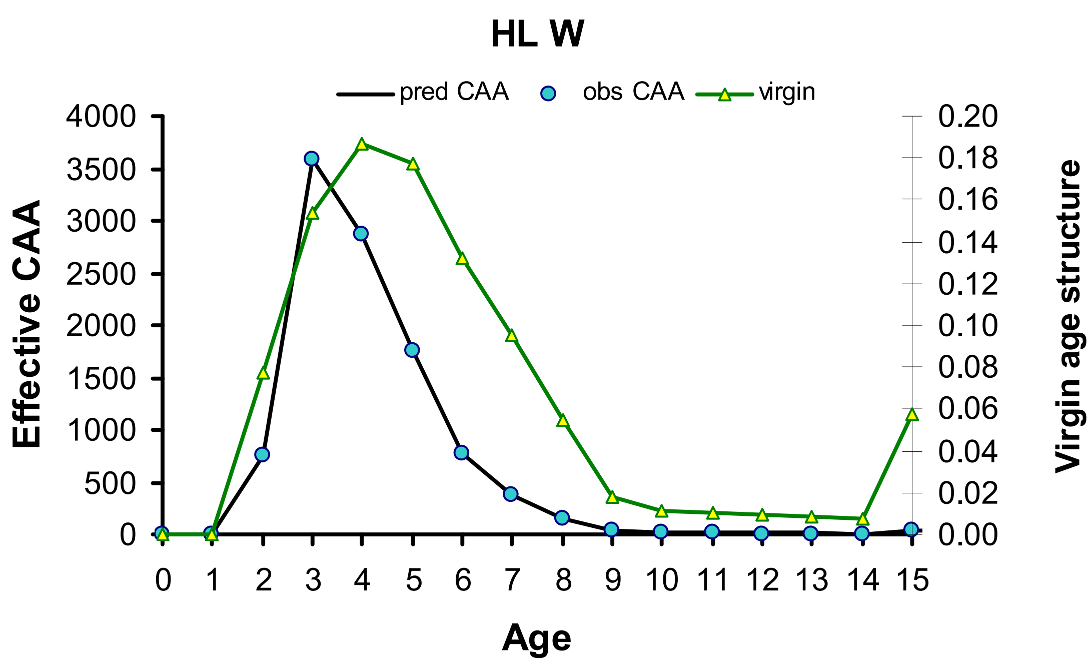


Figure AD4. Unexploited age frequency (virgin) versus exploited age frequency for the handline fishery in the East (a) and West (b). Age 15 is a plus group.

APPENDIX Generation Time & Spawning Abundance Comparisons

The attached spreadsheet gen time & ssb plots.xls provide calculations related to these issues.

APPENDIX CATCHEM Results

The attached spreadsheet Results.xls provide basic inputs and results for the CATCHEM age 0 and CATCHEM age 1